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1976

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SPECIAL REPORT 127

GEOLOGY AND ENGINEERING GEOLOGIC ASPECTS OF THE LAGUNA BEACH QUADRANGLE, ORANGE COUNTY, CALIFORNIA

by SIANG S. TAN and WILLIAM J. EDGINGTON
Geologists

1976

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Prepared in cooperation with the County of Orange Environmental Management Agency.

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SYNOPSIS OF GEO-ENVIRONMENTAL PROBLEMS

Slope Stability

Slope failure is the most critical geologic problem in the Laguna Beach quadrangle. Although the Vaqueros Formation, the Los Trancos Member of the Topanga Formation, and the Monterey Formation are the most landslide-prone bedrock units in the mapped area—no bedrock unit is completely devoid of landslides. Areas underlain by thin-bedded siltstones and shales show high incidences of landslides, mudflows, soil creep, and other ground movement (slope failure). Landslides and other slope failures seem to occur more often on north- and east-facing slopes. Rockfalls and rockglides have occurred frequently on steep slopes and sea cliffs in areas underlain by well-indurated sandstones and andesite; these sandstone beds occur primarily in the Topanga Formation but also occur in the San Onofre Breccia, Silverado, and Vaqueros Formations. All surficial deposits are poorly cemented and highly susceptible to rilling and ravelling, except for some better indurated portions of the marine terrace deposits and nonmarine cover on marine terraces. The San Onofre Breccia appears to be the most stable rock unit, followed by the Silverado and Sespe Formations.

Seismicity and Recency of Faulting

Earthquakes are the most widespread geo-environmental hazard in this area. The fault zones likely to cause major earthquake damage in this area are the San Andreas, the San Jacinto, the Elsinore-Whittier, and the Newport-Inglewood. The most severe ground response can be expected on the unconsolidated surficial deposits, especially in areas that have a high water table.

No evidence for Holocene fault movement was noted in the study. The only indication of late Pleistocene, or younger, faulting was found along three fault traces in the Pelican Hill fault zone in the Spy Glass Hill area.

Erosion

Erosion may be a problem on slopes underlain by loose, unconsolidated material such as slope wash, soil (not mapped in this study), artificial fill, and terrace, alluvial, and landslide deposits, particularly in areas of steep slopes and major drainage. Severe erosion by storm-waves along the coast and periods of high runoff frequently cause slope failure.

Expansivity

Areas most affected by the presence of expansive earth materials are those underlain by the Los Trancos Member of the Topanga Formation and by the Monterey and Capistrano Formations. This is also true for slope wash and landslide deposits derived from those units. Determination of expansivity and appropriate remedial measures should be required preceding construction in these areas.

Flood

Natural drainage systems are relatively small in the study area, except for Laguna Canyon and its unnamed tributary along El Toro Road and Aliso Creek. These drainages are subject to flooding during heavy rain storms.

Workability

The rock units mapped are generally easily to moderately easily excavated, except for some resistant sandstone beds in parts of the Topanga Formation (the Bommer Member and the undifferentiated Topanga Formation), the Silverado, the Sespe, and the Vaqueros Formations, and unweathered parts of intrusive rocks. The most prominent resistant sandstone beds are plotted separately on the geologic map as interpreted from aerial photographs.

Tsunami and Seiche

Tsunamis can affect coastal areas and such estuaries as Laguna Canyon and Aliso Creek. Threat to harbor facilities, public beaches, and near-shore structures, mainly in the Laguna Beach and Newport Beach areas, should be considered; but the sea cliff is a natural levee and will reduce the hazard.

Seiching, though unlikely, may occur in large bodies of water such as San Joaquin Reservoir and Big Canyon Reservoir. A strong seiche may overtop the San Joaquin Reservoir dam and flood Bonita Creek north of the studied area and its tributary, where the reservoir is located.

Mineral Resources

Ceramic clay, fill material, and sand and gravel resources should be assessed before urban development is allowed.

The sandy clay bed exposed along Shady Canyon is designated by a separate dashed line in the Silverado Formation on plate 1. The clay bed forms a dip-slope and is near the surface in 15-acre area at the eastern side of the northernmost part of Shady Canyon in the quadrangle. The quality of the clay was not tested in this study.

Fill material can be easily excavated from areas underlain by unconsolidated terrace and alluvial deposits.

The conglomeratic beds in the Sespe Formation may have some value as an aggregate source, but excessive fines in most places may restrict their use.

GEOLOGY AND ENGINEERING GEOLOGIC ASPECTS OF THE LAGUNA BEACH QUADRANGLE, ORANGE COUNTY, CALIFORNIA

By Siang S. Tan and William J. Edgington

INTRODUCTION

Purpose

The geology of the Laguna Beach quadrangle—which includes the San Joaquin Hills, the city of Laguna Beach, and the eastern portion of the city of Newport Beach—was studied during late 1971 and parts of 1972 and 1973. This study was done under a cooperative agreement between the California Division of Mines and Geology and the Orange County Department of Building and Safety, Road Department, and Flood Control District. The purpose of the study is to provide planners, geologists, and engineers with environmental and geologic data pertinent to efficient, safe, and intelligent use of the land and its resources. The geologic map should not be used for detailed planning of engineering structures or as a substitute for detailed site investigation; it is the product of a generalized regional study to delineate geologic features of possible engineering significance.

Method

Field mapping was plotted on the 1965 edition of the U.S. Geological Survey Laguna Beach 7.5-minute topographic quadrangle enlarged to a scale of 1:12,000 (1,000 feet to the inch). Aerial photographs at an approximate scale of 1:12,000 taken on July 30, 1970 (prepared by E.L. Pearson and Associates), and selected aerial photos of earlier dates were examined in this study. Several bulldozer trenches were examined at selected locations in cooperation with the California Division of Highways.

Half of the quadrangle (about 18 square miles) was investigated by William J. Edgington from 1971 to 1973; the remaining area, in the north central part of the quadrangle, was mapped by Siang S. Tan during April and May 1973.

Previous Studies

Mapping by J.G. Vedder, R.F. Yerkes and J.E. Schoellhamer (1957) of the U.S. Geological Survey was used to determine the basic geologic structure and as a basis for separating the bedrock units. The area was remapped to stress engineering geologic aspects and because recent exposures permitted new interpretations.

Geological mapping in four adjacent quadrangles, part of the same cooperative program from 1967 through 1972, was completed by P.K. Morton, W.J. Edgington, and D.L. Fife (1974) in the San Juan Capistrano quadrangle; by D.L. Fife (1974) in the El Toro quadrangle; by W.J. Edgington (1974) in the Dana Point quadrangle; and by P.K. Morton (1970, 1974) in the Cañada Gobernadora quadrangle.

Acknowledgments

Helpful information and data were received from: Oscar Stankov, California Division of Highways; R.D. Murphy, J.E. Slosson and Associates; F. Beach Leighton and Associates; D.N. Klemme, Moore and Taber; Geolabs; G. Nichol and Associates; Evans, Goffman, and McCormick; W.A. Wahler and Associates; Earth Sciences Associates; T.A. Sayers, Geosoils, Inc.; Thomas Howard, City of Laguna Beach Planning Department; C.E. Hollon, City of Newport Beach; Cecil Robinson, Santa Ana; Fred Pratley, Manley Natland, and Peter H. Gardett, Laguna Beach; and local governmental agencies. Cooperation of the landowners, The Irvine Company in particular, and their representatives is acknowledged.

Geography

In the Laguna Beach quadrangle, the elevation ranges from sea level to 1,164 feet. The topography consists mainly of the San Joaquin Hills, a broad gently rolling upland cut by moderately steep-sided canyons. The southwest flank of the San Joaquin Hills area is cut by straight canyons trending southwest to the ocean. Laguna Canyon, the major drainage in the region, trends southerly near the eastern edge of the quadrangle to the Pacific Ocean at Laguna Beach.

Marine wave-cut surfaces that slope gently to the southwest cover an area half a mile wide along the Pacific coast. Most of the city of Laguna Beach is located on one of these surfaces. The flat, broad, wave-cut terraces in the Newport Beach and Upper Newport Bay area form a mile-wide area along the western edge of the quadrangle that is largely urbanized.

Rainfall in the quadrangle averages between 11 and 15 inches annually, nearly all between October and May. The climate is Mediterranean to semi-arid with coastal oceanic influence diminishing rapidly inland.

GEOLOGIC SETTING

Regional Setting

The Laguna Beach quadrangle comprises a part of the northwestern flank of the Peninsular Ranges of southern California, including the major part of the San Joaquin Hills and the southeastern extremity of the large sedimentary basin known as the Los Angeles basin (Yerkes *et al.*, 1965, p. A1). The studied area is located at the southern part of the "Central (structural) Block" of the Los Angeles basin (Yerkes *et al.*, 1965, p. A5 and A15) 1 to 2 miles northeast of the offshore Newport-Inglewood fault zone, which forms the southwestern limit of this Central Block. The San Joaquin Hills are separated geographically from the Santa Ana Mountains by an alluvial basin northeast of the quadrangle.

Stratigraphy

The quadrangle is underlain by Paleocene through early Pliocene (or late Miocene) marine and nonmarine sedimentary rocks locally intruded by Miocene dikes and sills of andesite and diabase. All of these rocks are capped by Pleistocene and Holocene surficial units. This succession, in which abrupt facies changes are evident, attains a composite thickness of 22,000 feet (Vedder, 1970, p. 16).

The oldest rocks in the quadrangle, assigned to the Silverado Formation of Paleocene age, consist of marine and nonmarine coarse- to medium-grained sandstone and some conglomeratic sandstone and claystone. The Santiago Formation of Eocene age is composed of marine medium- to coarse-grained sandstone with interbedded fine-grained sandstone. The Silverado Formation seems to have a gradational contact with the overlying Santiago Formation, but the contact is described as an unconformity in some other areas of Orange County (Woodring *et al.*, 1945; Morton, 1970, 1974). Both formations are exposed in an upfaulted block in the Shady Canyon area.

Unconformably overlying these units are nonmarine strata of the Sespe Formation, which consist of coarse-grained clayey sandstones and conglomerates of late Eocene to early Miocene age. The Sespe Formation is unconformably overlain by marine beds of the Vaqueros Formation, which consists of siltstone, sandy siltstone, and fine- to coarse-grained sandstone, of early Miocene age.

The Vaqueros Formation is conformable and transitional with the overlying Topanga Formation of middle Miocene age. The Topanga Formation is composed of three members in the region west of the Laguna Canyon. In ascending order, these are: the Bommer Member, characterized by thick-bedded resistant coarse-grained sandstones; the Los Trancos Member, composed of thin-bedded siltstone and fine-grained sandstone; and the Paularino Member consisting of tuffaceous sandstone, siltstone, breccia, and flows. Clastic rocks that are older than the middle Miocene (the Bommer Member and older units) presumably were derived entirely from the eastern basement rock complex consisting of metasedimentary, metavolcanic, and plutonic rocks. Parts of the section may have come from source areas much farther east and north than the Santa Ana Mountains (Vedder, 1970, p. 16). Post middle Miocene sedimentary rocks (rocks younger than the Bommer Member), such as the San Onofre Breccia, contain varying amounts of clastic material derived from both the eastern and western basement complex sources. The western basement rock complex (Catalina Schist) consists primarily of thinly foliated and corrugated glaucophane-lawsonite-chlorite-albite schists and related rocks. In general, the western schist detritus diminishes in volume upward in the upper Miocene Monterey Formation and younger units and may be dominantly recycled from underlying middle Miocene sedimentary formations (Vedder, 1970, p. 16 and 17).

The middle Miocene marine and nonmarine San Onofre Breccia, characterized by fragments of Catalina Schist breccia, locally contains considerable sandstone, siltstone, and conglomerate. In general, the unit unconformably overlies the Topanga Formation, with local channelling into the Topanga Formation. However, the contact seems to be conformable and gradational in the sea cliffs southeast of Laguna Beach at Halfway Rock (Duggan, 1961, p. 22). It also appears that locally, along the Pelican Hill fault zone, the San Onofre Breccia has a gradational and interfingering contact with the Los Trancos Member of the Topanga Formation. This contact relationship is somewhat obscured by complex faulting and structure along the Pelican Hill fault zone.

Outcrops of the unconformably overlying Monterey Formation of middle to late Miocene age—composed chiefly of siliceous and tuffaceous shale, siltstone and calcareous sandstone—extend from Upper Newport Bay southward along the coast of Laguna Beach. These rocks grade upward into strata equivalent to the lower part of the Capistrano Formation of late Miocene to early Pliocene age that are present near Reef Point (Vedder, 1970, p. 17). The unit contains marine siltstone and fine-grained sand and shale and lithologically resembles the underlying Monterey Formation.

Gradual, interrupted emergence of the region from the sea occurring in Pleistocene times created numerous wave-cut terrace platforms, most of which were covered by marine deposits. The subsequent erosion of adjacent highlands provided a nonmarine colluvial cover that resembles what is mapped elsewhere in the quadrangle as slope wash deposits. Minor stream deposits of Pleistocene age flank major drainages in some areas. Younger surficial deposits of Holocene age are alluvial, pond, and slope wash deposits and beach sediments along the coast. Changes in climate and sea level during Late Quaternary time may have been partly responsible for the many unstable, oversteepened slopes and massive landslide deposits occurring along major canyons.

Structure

The main structural feature in the central San Joaquin Hills area has generally been described as a complexly faulted northerly plunging anticline; the Capistrano syncline borders it on the east (Vedder, 1970, p. 18). However, the so-called anticlinal structure is based on the relative regional arrangement of bedding attitude in the Topanga Formation, which was created by faulting rather than by folding. Moreover, a downdropped fault block with about 1,000 feet of vertical separation is present at the crest of the structure. The dominant factor in the regional structural arrangement in the quadrangle seems to be faulting rather than folding, since homoclinal structure is generally present in the faulted blocks. An exception to this is in the Monterey Formation where folding is apparent, especially in a complexly deformed 1-mile-wide zone along the Pelican Hill fault zone.

The quadrangle is transected by numerous northwest-trending faults including the Pelican Hill, Shady Canyon, and southern part of the Laguna Canyon fault zones, as well as the offshore Newport-Inglewood fault. North-trending faults, such as the northern portion of the Laguna Canyon fault, and east-trending faults, such as the Temple Hill fault, are also present.

The Pelican Hill fault zone moved vertically as well as laterally during Miocene and Pliocene times (Vedder, 1970, p. 18 and 19). The greatest stratigraphic displacement noted was in the Moro Canyon area, where the San Onofre Breccia and the Los Trancos Member of the Topanga Formation are faulted against the Vaqueros Formation so that about 2,500 feet of the Bommer Member of the Topanga Formation is cut out across this part of the fault. In the Spy Glass Hill development area, southwest of San Joaquin Reservoir, three fault traces in the Pelican Hill fault zone have displaced one of the higher level Pleistocene marine terrace deposits (elevation 470 to 600 feet). This indicates that the fault zone, or at least part of it, has moved as recently as late or post-Pleistocene time.

The Shady Canyon fault shows a stratigraphic separation of 5,000 feet(?) with the southwest side downthrown. Two episodes of movement during middle Miocene time are suggested by the emplacement and dislocation of diabase intrusions along the fault (Vedder, 1970, p. 19). The Topanga Formation and most of the Vaqueros Formation are missing on the uplifted northeast block, suggesting that this side may have been a positive area during Topanga and possibly part of Vaqueros time. The fault cuts only the very lowest beds of the late Miocene Monterey Formation just east of the quadrangle boundary (Morton *et al.,* 1974) so that the last movement along the Shady Canyon fault probably occurred in the late middle or early late Miocene time. The upthrown fault block in the Shady Canyon area, which is underlain by the Silverado Formation, is faulted against the Sespe Formation. The Santiago Formation, missing across the faults bordering this fault block, is more than 775 feet thick in the San Joaquin Hills area (Yerkes *et al.,* 1965, plate 1).

The Laguna Canyon fault zone consists partly of two essentially parallel northwest-trending normal faults southeast of Laguna Canyon; north of this canyon, the zone forms a single fault. The northeastern fault southeast of Laguna Canyon dips from 55° to 75° to the southwest with movement of the northeast block upward relative to the southwest block. An 1,850-foot vertical displacement across the fault near its junction with the Shady Canyon fault to the north is suggested by Bode (1934). Relative movement of the fault zone south of the Temple Hill fault appears to be in excess of 200 feet (Morton *et al.,* 1974). Duggan (1961, p. 1 and 2) proposed that the conformable contact between the Topanga Formation and San Onofre Breccia southwest of this fault zone and the comparable unconformable contact to the northeast (and east of the quadrangle) suggest post-Topanga pre-San Onofre Breccia movement along the Laguna Canyon fault with subsequent erosion followed by deposition of the San Onofre Breccia on the eroded older formations northeast of the fault. Recurrent movement along the Laguna Canyon fault occurred after deposition of the Topanga Formation and both before and after deposition of the San Onofre Breccia in this area because the fault cuts the San Onofre Breccia.

Quaternary, possibly limited to late Pleistocene, uplift of the area in the Laguna Beach quadrangle is believed to have occurred because eustatic changes of sea level cannot account for the amount of elevation of the higher marine terrace deposits above present sea level.

The base of terrace deposits in the San Joaquin Reservoir area is inclined 120 to 200 feet per mile to the north and northeast. Terrace deposits along the coast slope 120 to 180 feet per mile towards the ocean. It is not definitely known whether tectonic movements, original natural slope angle, irregularities of the wave-cut platforms, or a combination of these factors can account for the oppositely dipping terrace platforms. Palmer (1967, p. 365) called this phenomenon a "downwarping" of the terraces, which suggests a dominant tectonic role.

GEO-ENVIRONMENTAL PROBLEMS

Slope Stability

Slope stability is dependent on a multiplicity of factors and their interrelationships. Earth material (bedrock, debris, sediment, soil, etc.), related characteristics (porosity, fissibility, cohesive strength, shear strength, internal friction, etc.), and steepness of slope are probably the most important.

The fissibility characteristics of the rock—including bedding development, jointing, fracturing, faulting, and the configuration of these in relation to the topography—are particularly important. Rainfall, erosion, earthquakes, and man's activities (fill-cut, fire, water influx) amplify the effects of the unstable characteristics of the landscape or, in some cases, cause new ground failure. Many other factors contribute such as the density and type of vegetation and the position of slope relative to sun exposure.

The Laguna Beach quadrangle contains numerous landslides of a variety of ages, types, and sizes. No bedrock unit in the area is completely devoid of landslides. The highest incidence of landslides is in areas underlain by shale and siltstone.This is because shale and siltstone have properties such as high porosity which may cause high moisture content, low cohesive strength when wet, and generally thin bedding. The higher moisture content increases weight and plasticity, and consequently decreases slope stability.

The Vaqueros Formation, the Los Trancos Member of the Topanga Formation, and the Monterey Formation are the most landslide-prone bedrock units in the quadrangle. The finer-grained portions of the other geologic units, such as the undifferentiated Topanga Formation and the Bommer Member of the Topanga Formation, also contain many landslides. The San Onofre Breccia seems to be the most stable rock unit in the studied area, followed by the Silverado and Sespe Formations.

Most landslides in the Monterey Formation are modified rotational slumps or earthflows, although block-glide has occurred in areas of undercut bedding planes. Due to the thinly bedded and highly jointed nature of the Monterey Formation, most of these landslides have resulted in broken heterogeneous masses of debris with low stability characteristics.

Siltstone and shale beds of the Vaqueros Formation, the Los Trancos Member, and the undifferentiated Topanga Formation commonly fail as block-glides and rotational or earthflow landslides. These occur mainly in faulted sheared areas, particularly in the Pelican Hill fault zone. Siltstone lenses and interbeds in the San Onofre Breccia have also failed by rotational slumping and earthflows.

Commonly, landslides appear to occur more often on north- and east-facing slopes where evaporation rates are lower than on south- and west-facing slopes. The north- and east-facing slopes are characterized by more intense weathering, thicker soil mantle, grassy vegetation and more surficial failures such as soil creep and other earthflows.

Steepness of slope is another important factor affecting slope stability. Steep natural slopes affected by normal erosion usually consist of resistant material of high slope stability qualities. More gentle slopes may be composed of weaker material such as soil, debris, loose sediments, or weak bedrock having less favorable engineering (lithologic and structural) features.

Most of the larger landslides (more than 10 acres) are probably pre-historic. No dates have been established, but geomorphic appearance suggests ages roughly correlative to similar landslides in adjacent areas where they were dated from 10,000 to 20,000 years before the present (Morton *et al.*, 1974, p. 5; Stout, 1969, p. 173). Estimated rainfall for the period 14,000 to 15,000 years B.P. was more than double that of the present day (Stout, 1969, p. 175), and sea level was lower by several hundred feet. Curray (1965, p. 724) stated that the sea level between 20,000 and 17,000 B.P. was 120 to 125 metres lower than the present sea level. This combination of factors caused more rapid erosion along major canyons resulting in many oversteepened slopes; heavy rainfall may have triggered these massive landslides.

Most landsliding is expected to be related to previous landslide areas. However, slopes having marginal stability under present conditions obviously exist and massive failures may occur where grading for development and additional water from urban irrigation adversely affect those conditions.

Rockfalls and rockslides have occurred on sea cliffs and steep upland slopes, particularly in the resistant sandstones of the undifferentiated Topanga Formation and its Bommer Member. They occur also in areas of well-cemented resistant sandstones occurring in the Silverado Formation, San Onofre Breccia, Vaqueros Formation, and locally in the Monterey Formation, as well as the andesite intrusions along the sea cliffs. These failures are commonly too small to be mapped at the scale of 1:12,000, although they certainly can be damaging to engineering structures. They frequently occur on steep anti-dip slopes.

During the wet season, between October and May, heavy storms periodically occur in the region. Mud and debris flows occurred on steep slopes along Laguna Canyon during unusually heavy rains in 1938 and 1969. Similar failures have been triggered by heavy run-off on steep slopes with soil and rocky debris cover on nearly every bedrock formation throughout the quadrangle. Mappable amounts of the debris seldom remain, but scars on the hillsides are commonly visible for several years.

Stream alluvium, landslide debris, slope wash debris, pond deposits, beach sediments, and part of the nonmarine cover on marine terraces are unconsolidated to poorly consolidated and thus have poor slope stability and are very susceptible to rilling and ravelling. The other surficial units such as the marine terrace deposits, stream terrace deposits, and part of the nonmarine cover on marine terraces are generally slightly better consolidated and, therefore, have better slope stability qualities but are usually still subject to rilling and ravelling.

The failures in the lining of San Joaquin Reservoir in early 1973 were caused by failure and differential settlement of the artificial fill. Related bedrock failures were not observed. Some ground-water seepage from the interbedded sandstone-siltstone-shale behind the lining may have contributed to these failures (Warren D. Pedersen, California Division of Safety of Dams, oral communication, 1973).

Seismicity

This area of California lies in a seismically active zone. The fault zones in the region most likely to generate dam-

Table 1. Selected earthquakes potentially damaging to structures in southern California (Morton et al., 1974).

DATE	APPROXIMATE AREA OF ORIGIN	MODIFIED MERCALLI INTENSITY NEAR ORIGIN	MAGNITUDE
1769 July 28	Not known but noted by Portola expedition near mouth of Santa Ana Canyon	?	?
1812 Dec 8	Not known but severely damaged Missions San Juan Capistrano and Santa Ynez	IX-X	7*
1857 Jan 9	Fort Tejon region	X-XI	8.0*
1892 Feb	Baja California, Mexico	?	7.0*
1893 April 4	Newhall	VIII-IX	?
1899 Dec 25	San Jacinto-Hemet	IX	7.0*
1918 April 21	San Jacinto-Hemet	IX	7.0*
1923	San Bernardino	?	6.0*
1933 March 10	Long Beach (offshore)	IX	6.3*
1938 May 31	Santa Ana Mountains (Upper Trabuco Canyon)	VI	5.5
1956 Jan 3	Riverside County (Glen Ivy)	VI	4.7

*Estimated

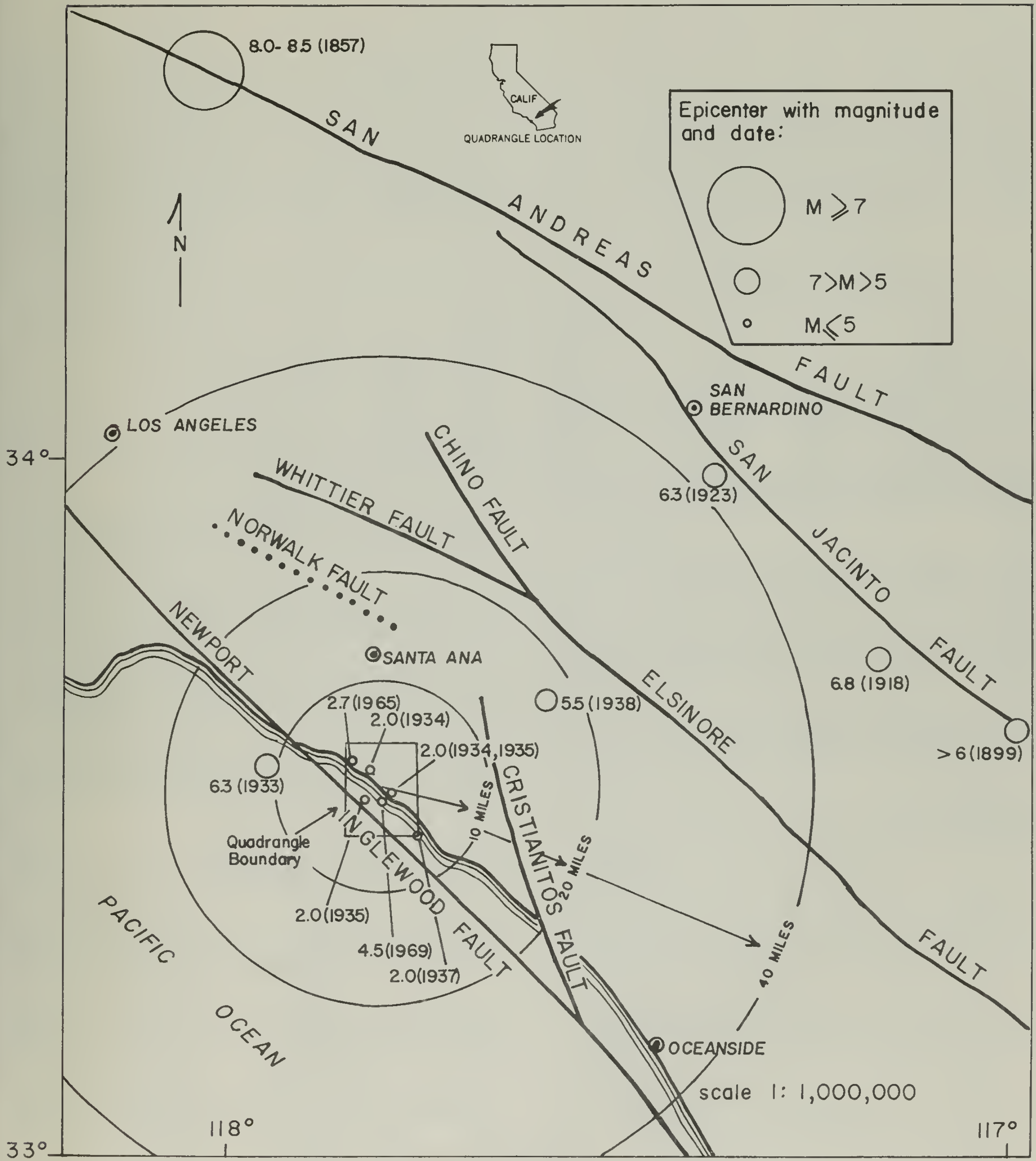
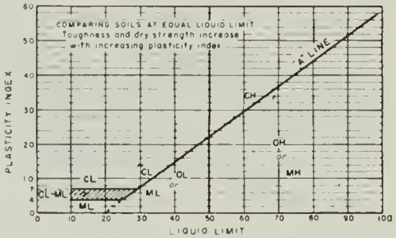


Figure 1. Map showing regional major faults and epicenters of historic earthquakes.

Table 2. Unified soil classification chart.

UNIFIED SOIL CLASSIFICATION
INCLUDING IDENTIFICATION AND DESCRIPTION

FIELD IDENTIFICATION PROCEDURES (Excluding particles larger than 3 inches and basing fractions on estimated weights)						GROUP SYMBOLS [1]	TYPICAL NAMES	INFORMATION REQUIRED FOR DESCRIBING SOILS	LABORATORY CLASSIFICATION CRITERIA			
COARSE GRAINED SOILS More than half of material is larger than No 200 sieve size [2] (The No 200 sieve size is about the smallest particle visible to the naked eye)	GRAVELS More than half of coarse fraction is larger than No 4 sieve size (For visual classifications, the ¼" size may be used as equivalent to the No 4 sieve size)	CLEAN GRAVELS (Little or no fines)	Wide range in grain size and substantial amounts of all intermediate particle sizes			GW	Well graded gravels, gravel-sand mixtures, little or no fines	Give typical name, indicate approximate percentages of sand and gravel, max size, angularity, surface condition, and hardness of the coarse grains, local or geologic name and other pertinent descriptive information, and symbol in parentheses For undisturbed soils add information on stratification, degree of compactness, cementation, moisture conditions and drainage characteristics EXAMPLE - Silty sand, gravelly, about 20% hard, angular gravel particles ½ in maximum size, rounded and subangular sand grains coarse to fine about 15% non-plastic fines with low dry strength, well compacted and moist in place, alluvial sand, (SM)	Use grain size curve in identifying the fractions as given under field identification	Determine percentages of gravel and sand from grain size curve Depending on percentage of fines (fraction smaller than No 200 sieve size) coarse grained soils are classified as follows - Less than 5% GW, GP, SW, SP More than 12% GM, GC, SM, SC 5% to 12% Borderline cases requiring use of dual symbols	$C_u = \frac{D_{60}}{D_{10}}$ Greater than 4 $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between one and 3	
			Predominantly one size or a range of sizes with some intermediate sizes missing			GP	Poorly graded gravels, gravel sand mixtures, little or no fines				Not meeting all gradation requirements for GW	
		GRAVELS WITH FINES (Appreciable amount of fines)	Non-plastic fines (for identification procedures see ML below)			GM	Silty gravels, poorly graded gravel sand-silt mixtures				Atterberg limits below "A" line, or PI less than 4	Above "A" line with PI between 4 and 7 are borderline cases requiring use of dual symbols
			Plastic fines (for identification procedures see CL below)			GC	Clayey gravels, poorly graded gravel sand-clay mixtures				Atterberg limits above "A" line with PI greater than 7	
	SANDS More than half of coarse fraction is smaller than No 4 sieve size	CLEAN SANDS (Little or no fines)	Wide range in grain sizes and substantial amounts of all intermediate particle sizes			SW	Well graded sands, gravelly sands, little or no fines				$C_u = \frac{D_{60}}{D_{10}}$ Greater than 6 $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between one and 3	
			Predominantly one size or a range of sizes with some intermediate sizes missing			SP	Poorly graded sands, gravelly sands, little or no fines				Not meeting all gradation requirements for SW	
		SANDS WITH FINES (Appreciable amount of fines)	Non-plastic fines (for identification procedures see ML below)			SM	Silty sands, poorly graded sand silt mixtures				Atterberg limits below "A" line or PI less than 4	Above "A" line with PI between 4 and 7 are borderline cases requiring use of dual symbols
			Plastic fines (for identification procedures see CL below)			SC	Clayey sands poorly graded sand-clay mixtures				Atterberg limits above "A" line with PI greater than 7	
	IDENTIFICATION PROCEDURES ON FRACTION SMALLER THAN No 40 SIEVE SIZE											
			DRY STRENGTH (CRUSHING CHARACTERISTICS)	DILATANCY (REACTION TO SHAKING)	TOUGHNESS (CONSISTENCY NEAR PLASTIC LIMIT)							
FINE GRAINED SOILS More than half of material is smaller than No 200 sieve size	SILTS AND CLAYS Liquid limit less than 50		None to slight	Quick to slow	None	ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands with slight plasticity	Give typical name, indicate degree and character of plasticity, amount and maximum size of coarse grains color in wet condition odor if any, local or geologic name, and other pertinent descriptive information, and symbol in parentheses For undisturbed soils add information on structure, stratification, consistency in undisturbed and remolded states, moisture and drainage conditions EXAMPLE - Clayey silt, brown, slightly plastic, small percentage of fine sand, numerous vertical root holes, firm and dry in place, loess, (ML)			 PLASTICITY CHART FOR LABORATORY CLASSIFICATION OF FINE GRAINED SOILS	
			Medium to high	None to very slow	Medium	CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays					
			Slight to medium	Slow	Slight	OL	Organic silts and organic silt clays of low plasticity					
	SILTS AND CLAYS Liquid limit greater than 50		Slight to medium	Slow to none	Slight to medium	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts					
			High to very high	None	High	CH	Inorganic clays of high plasticity, fat clays					
			Medium to high	None to very slow	Slight to medium	OH	Organic clays of medium to high plasticity					
HIGHLY ORGANIC SOILS			Readily identified by color, odor, spongy feel and frequently by fibrous texture			Pt	Peat and other highly organic soils					

[1] Boundary classifications Soils possessing characteristics of two groups are designated by combinations of group symbols For example GW-GC, well graded gravel-sand mixture with clay binder

[2] All sieve sizes on this chart are US standard

FIELD IDENTIFICATION PROCEDURES FOR FINE GRAINED SOILS OR FRACTIONS

These procedures are to be performed on the minus No 40 sieve size particles, approximately $\frac{1}{64}$ in For field classification purposes, screening is not intended, simply remove by hand the coarse particles that interfere with the tests

DILATANCY (Reaction to shaking)

After removing particles larger than No 40 sieve size, prepare a pat of moist soil with a volume of about one-half cubic inch Add enough water if necessary to make the soil soft but not sticky

Place the pat in the open palm of one hand and shake horizontally, striking vigorously against the other hand several times A positive reaction consists of the appearance of water on the surface of the pat which changes to a livery consistency and becomes glossy When the sample is squeezed between the fingers, the water and gloss disappear from the surface, the pat stiffens, and finally it cracks or crumbles The rapidity of appearance of water during shaking and of its disappearance during squeezing assist in identifying the character of the fines in a soil

Very fine clean sands give the quickest and most distinct reaction whereas a plastic clay has no reaction Inorganic silts, such as a typical rock flour, show a moderately quick reaction

DRY STRENGTH (Crushing characteristics)

After removing particles larger than No 40 sieve size, mold a pat of soil to the consistency of putty, adding water if necessary Allow the pat to dry completely by oven, sun, or air drying, and then test its strength by breaking and crumbling between the fingers This strength is a measure of the character and quantity of the colloidal fraction contained in the soil The dry strength increases with increasing plasticity

High dry strength is characteristic for clays of the CH group A typical inorganic silt possesses only very slight dry strength Silty fine sands and silts have about the same slight dry strength, but can be distinguished by the feel when powdering the dried specimen Fine sand feels gritty whereas a typical silt has the smooth feel of flour

TOUGHNESS (Consistency near plastic limit)

After removing particles larger than the No 40 sieve size, a specimen of soil about one-half inch cube in size is molded to the consistency of putty If too dry, water must be added and if sticky, the specimen should be spread out in a thin layer and allowed to lose some moisture by evaporation Then the specimen is rolled out by hand on a smooth surface or between the palms into a thread about one-eighth inch in diameter The thread is then folded and rerolled repeatedly During this manipulation the moisture content is gradually reduced and the specimen stiffens, finally loses its plasticity, and crumbles when the plastic limit is reached

After the thread crumbles, the pieces should be lumped together and a slight kneading action continued until the lump crumbles

The tougher the thread near the plastic limit and the stiffer the lump when it finally crumbles, the more potent is the colloidal clay fraction in the soil Weakness of the thread at the plastic limit and quick loss of coherence of the lump below the plastic limit indicate either inorganic clay of low plasticity, or materials such as kaolin-type clays and organic clays which occur below the A-line

Highly organic clays have a very weak and spongy feel at the plastic limit

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aging earthquakes (with their closest proximity to the quadrangle) are the San Andreas (43 miles), San Jacinto (37 miles), Elsinore-Whittier (12 miles) and the Newport-Inglewood (1 mile) fault zones.

Three earthquake epicenters have been located instrumentally on land in the quadrangle, and three epicenters have been located less than 1 mile off the coast. These earthquakes had magnitudes less than 4 except for a magnitude 4.5 event located offshore 2 miles west of the city of Laguna Beach on October 27, 1969. At least three earthquakes, including the strongest 1969 earthquake, could be related to the Pelican Hill fault system, as they are located in or near this fault zone; however, the epicenters are thought to be accurate only within 5 to 15 kilometres.

The most severe ground response can be expected on unconsolidated surficial deposits such as alluvial, landslide, and terrace deposits, especially in areas with a high water table such as the low areas along the bottom of Laguna Canyon and Aliso Creek. Liquefaction may also occur at these localities during a severe earthquake. Less severe ground shaking could occur in the more resistant bedrock units. Slope failure may be triggered, not only in areas of existing landslide, earthflow, and other slope failures, but also on slopes having marginal stability, particularly in developed areas where grading and water influx have had an adverse effect.

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KEY TO MAP UNIT CHARACTERISTICS

NAME OF MAP UNIT AND SYMBOL

TERRAIN FEATURES

Topographic expression: Each geologic unit weathers and erodes in a characteristic way resulting in a unique topographic expression.
Vegetation: Type of vegetation naturally occurring on this map unit. Water retention and root foundation of flora strongly influence vegetative occurrence.
Approximate natural slope angle range: Appropriate range based on observations.
Slope-wash development: Degree to which weathered, disintegrated debris from the unit tends to accumulate; nature of debris.
Soil development: General soil characteristics.

LITHOLOGIC FEATURES

Type and color: Predominant rock types listed in order of abundance. Color designations are according to the Munsell/Geological Society of America System Rock Color Chart (Goddard *et al.*, 1951).
Bedding: Degree and character of planar arrangement of sediments resulting from original depositional mode of accumulation.
Induration and/or consolidation: Degrees of hardness or compaction and character of cementation if present.
Angularity: Estimation of angularity or roundness of grains and clasts occurring in the unit.
Sorting: Degree of size similarity of individual grains occurring in the sedimentary units (e.g., well-sorted indicates all particles are similar in size).
Composition: General composition. Based upon field observations and selected microscopic analyses.
Structure: Arrangement or configuration of bedding, jointing, fractures, or other planar features of rock units.
Thickness: Maximum dimension of accumulation of the unit measured perpendicular to the bedding.
Contact relations: Nature of the interface between contiguous rock units.
Age and fossils: Geologic age and significant fossil occurrences within the Laguna Beach quadrangle and in adjacent quadrangles.

ENGINEERING FEATURES

Unified soil classification: Size classification of grains and clasts occurring in the sedimentary units if the material is in a disaggregated state (As adopted by the Corps of Engineers and Bureau of Reclamation).
Workability: Ease of excavation by commonly used equipment.
Slope stability: Stability of the rock unit and type of failure.
Permeability: Designation of ease of water movement through the rock unit based upon visual inspection.
Porosity: Designation of degree of water absorption capability based upon visual inspection.
Density: Dry weight per unit volume in pounds per cubic foot (pcf).
Expansivity: Empirical designation of degree of expansion when wetted.
Structural fabric: Structural grain of the materials as a whole by arrangement of linear or planar elements such as beds, joints, fractures, lineation of mineral grains.
Erodibility: Degree of susceptibility to erosion.
Other: Additional factors of note.

USE POTENTIAL

Sand and gravel: Amenability for use as aggregate or road base.
Fill: Amenability for use as fill materials of various types.
Waste disposal sites: General evaluation of the gross aspects of the formation relative to siting of class II and III waste disposal sites (as adopted by the California State Water Resources Control Board, 1972)
Aquifer: Evaluation of potential as a reservoir rock for ground water.
Other: Possible or suggested commercial mineral resource potential of materials within the rock unit.

NOTES

1. The use of the designation of degree—such as "high", "very high", "moderately high"—of the map unit characteristics as indicated in the following tables is subjective, based upon empiricism. It is an attempt to summarize qualitative pertinent data of possible environmental-engineering significance for each map unit.
2. The tabulated description of the map units is mainly based on the work of Morton *et al.* (1974) in San Juan Capistrano quadrangle, to the east. Many data in the geologic unit characteristics have been taken from that report because they apply equally well to this area.
3. Most of the Quaternary pond deposits are under water and could not be investigated. The characteristics of these deposits, which are generally slope wash deposits submerged by man-made dams or natural causes, may not differ much from those of the slope wash deposits that are tabulated in the present report. However, stratification of sediments and thin-bedded clay and silt may be more profound in the pond sediments.

MAP UNIT CHARACTERISTICS

ALLUVIUM (Qal)

TERRAIN FEATURES

Topographic expression: Flat area, occurs only in present drainage channels and flood plains. Only mapped along Laguna Canyon, El Toro Road, and Aliso Creek. Minor occurrences mapped as slope-wash deposit.
Vegetation: Oak, sycamore, willow, wild tobacco, and annual grasses.
Approximate natural slope angle range: 0° to 3°, excepting steeper channel-cut banks.
Slope-wash development: Absent.
Soil development: Mostly absent.

LITHOLOGIC FEATURES

Type and color: Light gray to yellowish-gray fine to coarse sand, gravel, and silt.
Bedding: Crossbedded and lenticular, commonly graded bedding.
Induration: Unconsolidated to poorly consolidated.
Angularity: Mostly angular to subangular sand with subangular to rounded gravel fraction.
Sorting: Poorly sorted over-all, but variable.
Composition: Quartzo-feldspathic lithic sand and clasts. Qal along Laguna Canyon and El Toro Road is derived from Ts and Tt; Qal along Aliso Creek is derived from Tt, Tso, Tm and Ts.
Structure: Flat-lying.
Thickness: Variable but reaches as much as 100 feet near mouths of Laguna Canyon and Aliso Creek.
Contact relations: Rests in channels cut on bedrock units.
Age: Holocene; still being deposited at present time.

ENGINEERING FEATURES

Unified soil classification: Variable, but mostly SM, SP, GW, GM.
Workability: Easily excavated with light equipment.
Slope stability: Poor where sloped, but normally underlies flat terrain.
Permeability: Very high.
Porosity: Variable, but generally moderately high.
Density: Variable. Ranges from about 90 pcf for SM to 120 pcf for GW.
Expansibility: Negligible to low.
Structural fabric: Negligible.
Erodibility: Very high on slopes greater than 5°.

USE POTENTIAL

Sand and gravel: Low, due to limited areal extent.
Fill: Good for pervious fill, but limited extent.
Waste disposal sites: Low, due to ground water mobility (very high permeability and high water table).
Aquifer: High to moderate, but limited in extent. Several producing wells in Laguna Canyon.

SLOPE WASH (Qsw)

TERRAIN FEATURES

Topographic expression: Broad, gently inclined aprons at or near the bases of slopes. Minor occurrence of alluvium is mapped as Qsw, particularly along Laguna Canyon.
Vegetation: Variable. Tends to reflect characteristics of bedrock source.
Approximate natural slope angle range: 0° to 10°.
Slope-wash development: —
Soil development: Generally absent except for transported soil.

LITHOLOGIC FEATURES

Type and color: Variable. Reflects bedrock source.
Bedding: Absent or very poor stratification.
Induration: Unconsolidated.
Angularity: Variable. Reflects bedrock source.
Sorting: Variable. Reflects bedrock source.
Composition: Variable. Reflects bedrock source and contains a moderate amount of organic debris; consists of bedrock debris and transported soil.
Structure: Absent.
Thickness: Ranges from barely perceptible up to 30 feet. Thickest at base of slope.
Contact relations: Mantles bedrock at and near bases of slopes.
Age: Holocene. Still forming at present time.

ENGINEERING FEATURES

Unified soil classification: Variable. Reflects bedrock source.
Workability: Easily excavated.
Slope stability: Poor. Subject to slump, mudflow, and creep on moderate slopes.
Permeability: Moderate to high depending on bedrock source.
Porosity: Variable. Reflects bedrock source.
Density: Low to moderate. Usually has lower density than bedrock source.
Expansibility: Variable but tends to be higher than bedrock source.
Structural fabric: Absent.
Erodibility: High on moderate or steeper slopes.

USE POTENTIAL

Sand and gravel: Generally none.
Fill: Generally low unless blended (see Expansibility).
Waste disposal sites: Low due to thinness and proximity to ground water courses.
Aquifer: Generally low and limited in extent, but high to moderate along Laguna Canyon where several producing wells are present.

BEACH SEDIMENTS (Qb)

TERRAIN FEATURES

Topographic expression: Flat to very low, gentle slopes at ocean shoreline.
Vegetation: Barren.
Approximate natural slope angle range: 0° to 5°.
Slope-wash development: None.
Soil development: None.

LITHOLOGIC FEATURES

Type and color: Light gray, yellowish-gray, pale yellowish-brown, pale dusky-yellow medium-fine sand, silty sand with local coarse sand and gravel.
Bedding: Lenticular and poorly developed.
Induration: Unconsolidated and cohesionless.
Angularity: Subrounded to rounded.
Sorting: Moderate to well-sorted.
Composition: Predominantly quartz, feldspars and quartzite with some lithic grains and local gravel and shell debris.
Structure: —
Thickness: Thin to a few tens of feet on well-developed beaches.
Contact relations: Unconformable on bedrock units.
Age: Holocene. Still being deposited at present time.

ENGINEERING FEATURES

Unified soil classification: SP, SM (indicated by Qbs or Qb on map); GP, GM and GW (indicated by Qbg on the map).
Workability: Easily graded except where saturated.
Slope stability: Very poor, especially where saturated.
Permeability: High.
Porosity: Moderately high to high.
Density: Medium to moderately high for unconsolidated sediments.
Expansibility: Nonexpansive.
Structural fabric: None.
Erodibility: Easily eroded by wind and water.
Other: Subject to liquefaction in SP and SM.

USE POTENTIAL

Sand and gravel: Low; limited amounts and generally unavailable due to location.
Fill: Low; limited amounts, poor compaction characteristics, no binding clayey material (cohensionless) but good for pervious fills.
Waste disposal sites: None, due to poor location, high permeability, and small size of deposits.
Aquifer: None, due to poor location, small size of deposits, and saturation by seawater.

LANDSLIDE DEPOSITS (Qls)

TERRAIN FEATURES

Topographic expression: Hummocky and subdued terrain, commonly with abrupt rise on upslope boundary; lower and lateral boundaries commonly crowd, divert, or block drainage; commonly contains undrained depressions.
Vegetation: Commonly grassy with abundant mustard and wild tobacco. Phreatophytes common near base and undrained depression.
Approximate natural slope angle range: Variable but less than surrounding terrain.
Slope-wash development: Rapid accumulation of debris derived from broken-up and unconsolidated landslide materials.
Soil development: Depth of soil on ancient landslides commonly is much thicker than on natural bedrock areas due to increased fracturing and heavy influx of slope-wash.

LITHOLOGIC FEATURES

Type and color: Variable. Depends on bedrock source.
Bedding: Absent. Undrained depressions are commonly covered by well-bedded but thin clayey materials.
Induration: Very poor in most recent slides to moderately poor in ancient slides.
Angularity: Very angular to blocky except in block-glide slides which tend to remain semicoherent.
Sorting: Generally poor, depending on source material and type of failure.
Composition: Depends on source rock; contains broken rock fragments and possible clayey gouge along failure surface.
Structure: Generally chaotic except in block glides. Highly plastic materials such as Monterey shales subject to tight, contorted folding.
Thickness: Variable. Landslides indicated on attached map are usually more than 10 feet thick.
Contact relations: Configuration of failure surface is variable but generally gently- to moderately-inclined, broadly planar, or semi-concave with thin clayey-gouge along failure surface.
Age: Holocene to late Pleistocene. Larger landslide may have occurred between 10,000 and 20,000 B.P. (Stout, 1965; Morton *et al.*, 1974).

ENGINEERING FEATURES

Unified soil classification: Variable. Depends on source material (see Composition).

Workability: Easily excavated with light power equipment. Landslide may contain large, well-cemented fragments, particularly in block glides.
Slope stability: Highly susceptible to creep, slump, mudflow, and renewed movement, especially if undercut near toe or subject to high influx of water or loading by fill on upper part of landslide. Ancient slides tend to be less susceptible to renewed movement than recent slides.
Permeability: Generally high.
Porosity: High.
Density: Variable. Generally lower than source material.
Expansibility: Due to rapid soil development, commonly expansive where derived from clayey bedrock.
Structural fabric: Generally absent. In block glides, it depends on source rock, but material generally more fractured and broken up.
Erodibility: Very high due to fractured, broken-up material and rapid weathering.

USE POTENTIAL

Sand and gravel: Very low.
Fill: Variable. Depends on bedrock source and type of failure.
Waste disposal sites: Very large landslides can be adapted to this use if careful planning considers the poor slope stability features.
Aquifer: Commonly a limited source of ground water. Springs often occur at the bases of larger slides.

STREAM TERRACE DEPOSIT (Qt)

TERRAIN FEATURES

Topographic expression: Bench-like platform areas flanking large drainages. Minor occurrence in an area of about three acres along the northernmost portion of Coyote Canyon in the quadrangle.
Vegetation: Largely grass covered with some low brush.
Approximate natural slope angle range: 1° to 20°.
Slope-wash development: Contributes moderate amounts of cobbly, silty slope wash on slopes.
Soil development: Fairly well-developed clay loam on flatter slopes.

LITHOLOGIC FEATURES

Type and color: Pale reddish-brown to yellow-brown silty to clayey gravel with clayey silt and sand lenses.
Bedding: Crudely bedded and crossbedded, reflecting irregular river channel filling and cutting.
Induration: Poorly cemented but well consolidated.
Angularity: All degrees of angularity.
Sorting: Very poor (well graded) generally with locally well-sorted lenses. Average size of clasts 1 inch to 4 inches but range to 1 foot boulders.
Composition: Strongly lithic, clayey, quartzo-feldspathic matrix. Clasts reflect eastern bedrock source (metasedimentary, metavolcanic rock, and weathered granodiorite and tonalite).
Structure: Flat to very gently dipping.
Thickness: 40 feet.
Contact relations: Lower contacts dip gently towards canyon bottom. Some sharp channeling may occur. Overlain by Qsw.
Age: Late Pleistocene; C_{14} date on similar material at Plano Trabuco near the Cristianitos fault was dated as greater than 32,600 years (Morton *et al.*, 1974).

ENGINEERING FEATURES

Unified soil classification: GM, GC with minor SM, SC.
Workability: Moderately easily excavated with heavy power equipment.
Slope stability: Generally stable; will stand in vertical cuts but subject to rockfall failures.
Permeability: Moderately low; locally high where clay content is low and sorting is good.
Porosity: Moderate.
Density: Medium to moderately high for sedimentary materials (120 to 145 pcf).
Expansibility: Residual soils expansive.
Structural fabric: Minimal. Reacts massively.
Erodibility: Moderately low.

USE POTENTIAL

Sand and gravel: Low due to excessive fines. Clasts are sound.
Fill: Generally good.
Waste disposal sites: Low because of proximity to main drainage and limited extent.
Aquifer: Low due to limited extent.

NONMARINE DEPOSITS ON MARINE TERRACES (Qtn)

TERRAIN FEATURES

Topographic expression: Level to gently sloping, with some local relief due to steep-sided erosional rills. Relief also at top of sea cliffs.
Vegetation: Sparse grass and moderate brush cover.
Approximate natural slope angle range: 0° to 5°.
Slope-wash development: Little to none. Qtn resembles older slope-wash deposits.
Soil development: Moderate, 5 feet or more thick, reddish- and grayish-brown massive loamy sand and sandy loam with pale-brown and reddish-brown massive to blocky sandy loam and sandy clay subsoil; locally calcareous.

LITHOLOGIC FEATURES

Type and color: Grayish-red, reddish-brown, moderate to yellowish-brown, and brownish-gray silty clay, clayey silt with some silty sand, and sandy silt and gravel.
Bedding: Poorly bedded.
Induration: Poorly indurated and poorly consolidated; however, locally better indurated than underlying marine terrace deposit.
Angularity: Sand and gravel are subangular to rounded.
Sorting: Poorly sorted.
Composition: Clay contains considerable montmorillonite; silt and sand are mostly quartz, feldspars, and lithic grains; clasts include quartzite, volcanic rocks and schistose debris from the San Onofre Breccia.
Structure: Flat lying to very gently dipping.
Thickness: 20 feet.
Contact relations: Unconformable on marine terrace deposits and locally on marine-cut terraces in Tertiary formations.
Age: Pleistocene (Vedder *et al.*, 1957); possibly late Pleistocene.

ENGINEERING FEATURES

Unified soil classification: CL, ML, minor SM, GC, GM.
Workability: Easily graded.
Slope stability: Fair to poor; locally supports low steep slopes with minor sloughing.
Permeability: Low to moderate.
Porosity: Medium to moderately high.
Density: Low to moderate; 75 to 95 pcf dry density.
Expansibility: Moderately to slightly expansive.
Structural fabric: Generally massive; surficial cracks similar to moderate jointing due to expansive clay.
Erodibility: Subject to severe rilling, piping and ravelling.

USE POTENTIAL

Sand and gravel: Poor to none due to excessive fines and generally limited thickness.
Fill: Fair to good for fill; expansive nature may limit use.
Waste disposal sites: Poor due to limited extent and poor location near seacoast on elevated benches and near residential areas.
Aquifer: Poor; low permeability and limited extent.

MARINE TERRACE DEPOSIT (Qtm)

TERRAIN FEATURES

Topographic expression: Very gently sloping to level bench-like surfaces with some local relief due to scattered sand mounds and steep-sided erosional rills.
Vegetation: Sparse grass and light to moderate brush cover.
Approximate natural slope angle range: 0° to 2°.
Slope-wash development: Generally poor, but may cover fairly broad areas on tops of ridges and gentle slopes near Qtm.
Soil development: As much as 20 inches thick, pale brown, massive to blocky, sandy loam commonly with yellowish-brown, blocky, sandy clay subsoil, locally with pale brown silty sand subsoil, locally calcareous.

LITHOLOGIC FEATURES

Type and color: Light-brown to yellowish-brown fine sand and silty sand. Locally with gravel, especially near the base.
Bedding: Poorly bedded, lenticular, and crossbedded.
Induration: Loose to locally weakly cemented, poorly consolidated.
Angularity: Subrounded to rounded.
Sorting: Moderately well sorted.
Composition: Quartz and feldspar with some lithic grains including schistose debris from the San Onofre Breccia.
Structure: Flat lying to very gently dipping.
Thickness: 140 feet thick on Pelican Hill and 120 feet in San Joaquin Reservoir region.
Contact relations: Unconformable under nonmarine terrace deposits (Qtn). Unconformable on older rock formations; generally flat lying to very gently sloping contacts with local irregularities.
Age: Pleistocene (Vedder *et al.*, 1957).

ENGINEERING FEATURES

Unified soil classification: SP and SM, minor GP.
Workability: Easy to moderately difficult.
Slope stability: Poor to fair due to poorly consolidated nature, but locally good where consolidated; e.g., in the Spy Glass area (southwest of San Joaquin Reservoir) the thick marine terrace deposits seem to have moderate to good slope stability on man-made cut slopes; however, they are subject to rilling.
Permeability: Generally high.
Porosity: Moderate to high.
Density: Low to moderate; 80 to 100 pcf dry density.
Expansibility: Nonexpansive.
Structural fabric: Mostly none; cemented consolidation cracks locally.
Erodibility: Mostly easily eroded by rilling and locally by winds where uncemented.

USE POTENTIAL

Sand and gravel: Poor; limited in quantity, especially true of good aggregate gravel.
Fill: Good for fill, especially pervious fill.
Waste disposal sites: Poor; limited in extent; high permeability and poor location near seacoast at high elevation and residential areas.
Aquifer: Poor; limited in extent and located on top of hills and ridges. However, at the lower terraces, the marine deposits overlain by Qtn may contain some very limited ground water resources.

CAPISTRANO FORMATION (Tc)

TERRAIN FEATURES

Topographic expression: Moderate steepness with well-rounded topography, often with steep faces along canyons and sea cliffs.

Vegetation: Mainly grasses with light brush.
Approximate natural slope angle range: Ranges mostly between 10° to 30°.
Slope-wash development: Moderate to slight development of silty clay slope wash.
Soil development: Widespread cover of dark, grayish-brown adobe. Steep slopes are generally barren.

LITHOLOGIC FEATURES

Type and color: Marine, yellow-gray to light brownish-gray siltstone with interbedded lenticular white fine-grained sandstone and shale. Locally diatomaceous, siliceous, calcareous, and tuffaceous. Contains some limestone concretions. Tc closely resembles Tm.
Bedding: Mostly poorly bedded to massive. Diatomaceous and tuffaceous rocks are well-bedded and commonly fissile.
Induration: Moderately well indurated if dry; very soft when saturated.
Angularity: Sandstones: subangular to subrounded.
Sorting: Very well to moderate.
Composition: Quartzo-feldspathic with abundant biotite; montmorillonite clay fraction. Secondary gypsum deposited along joints, fractures, shears, and bedding planes.
Structure: Highly jointed and fractured. Bedding is well developed.
Thickness: Only the lower part of Tc (less than 100 feet thick) is exposed in the quadrangle.
Contact relations: Appears to be unconformable but locally gradational on Monterey Formation. Tc is the youngest bedrock unit within the quadrangle.
Age and fossils: Contains late Miocene to early Pliocene Foraminifera. Megafossils are sparse.

ENGINEERING FEATURES

Unified soil classification: Generally ML, CL to SC, SM (if disaggregated).
Workability: Moderately easily excavated with light power equipment, but will mire equipment if saturated.
Slope stability: Subject to creep, mudflow, and landslide on slopes of moderate to high steepness under heavy moisture conditions. Very low shear strength when saturated.
Permeability: Low except in friable sand lenses where it is moderate.
Porosity: Generally high.
Density: Medium in average material (90 to 115 pcf). Low in diatomaceous-tuffaceous areas (70 to 90 pcf).
Expansibility: Moderately expansive where clayey. Clay fractions have high montmorillonite content.
Structural fabric: Jointing, spaced at 1 foot to 3 feet with locally varying attitudes, is usually dominant; commonly jointed in two or more directions. Bedding generally is a secondary factor except in diatomaceous-tuffaceous beds.
Erodibility: Fair to poor, friable sand lenses ravel and rill. Siltstone is susceptible to piping.

USE POTENTIAL

Sand and gravel: None.
Fill: Variable. Clayey materials poor due to expansibility, etc.; diatomaceous materials poor due to low densities. Sandy silts good. In general, Tc is more acceptable if blended with sand.
Waste disposal sites: Good due to ease of excavation and low permeability. Areal extent is very limited but Tc is located in the larger Tm area which has similar characteristics.
Aquifer: Low due to low permeability.
Other: Soil mantle on Tc may be useful as a topsoil base for landscaping.

MONTEREY FORMATION (Tm, Tm–ss)

TERRAIN FEATURES

Topographic expression: Rounded, gently rolling hills, locally with steep, sloughing faces along larger canyons and sea cliffs and with bouldery outcrops.
Vegetation: Grassland with abundant mustard, locally with sparse to medium density brush, prickly pear and cholla cactus. Dry-farmed in some areas northwest of city of Laguna Beach.
Approximate natural slope angle range: Generally 7° to 20°; tends to be least on dip slopes and greatest on anti-dip slopes.

Slope-wash development: Generally thick accumulations on shale and siltstone; may reach 25 feet; usually highly plastic clay.

Soil development: Commonly 3 feet to 5 feet thick. Usually highly plastic dark brown adobe with calcareous subsoil clay. Forms uniform cover in most areas but little or no soil cover on many steep slopes.

LITHOLOGIC FEATURES

Type and color: Marine, white to yellowish-gray siliceous and tuffaceous shale, cherty shale, and siltstone with minor limy sandstone lenses and beds (Tm-ss); locally with limy concretions and minor limestones.

Bedding: Very thinly bedded; locally rhythmically bedded; commonly contorted.

Induration: Generally well indurated; cemented sandstone interbeds are very hard resistant materials; shale and siltstone become soft when saturated.

Angularity: Sandstones: subangular.

Sorting: Sandstones: poor.

Composition: Siltstone and shale: diatomaceous, siliceous, and tuffaceous with minor phosphatic lenses; montmorillonite clay common; minor palygorskite in fractures. Sandstone: quartzo-feldspathic with abundant glaucamphibole and quartzite lithic grains; calcareous.

Structure: The bedding generally dips to the northeast and north, with many local open and tight folds, and severe deformation along faults.

Thickness: Probably more than 2,500 feet thick east of Corona del Mar and southwest of Pelican Hill fault.

Contact relations: Gradational and locally interfingering contact with underlying San Onofre Breccia; locally unconformable contact with underlying Topanga Formation. Gradational contact with overlying Capistrano Formation.

Age and fossils: Siltstones and shale (the upper part of the formation) contain upper Miocene forams (Luisian and Mohnian). Lower section contains sandstone with megafossils suggestive of slightly older stages. *Pecten crassicardo* and *Vaquerosella* cf *merriami* (Morton *et al.*, 1974).

ENGINEERING FEATURES

Unified soil classification: SM, ML to CL, CH (when disaggregated).

Workability: Siltstone and shale can be graded easily with light power equipment. Sandstone can be removed by heavy power equipment, but may locally require blasting. Siltstone and shale mire equipment when saturated.

Slope stability: Siltstone and shale very poor; both bedrock and surficial failures are common; creep and gravity folding are common. Sandstone: poor, because closely associated with siltstone and shale. Low shear strength when saturated.

Permeability: Generally very low; locally moderate due to extensive jointing, closely spaced fractures and cleavage (bedding joints), and occurrences of sandstone lenses and interbeds.

Porosity: Very high in low density siltstone and shale; moderate to low in cherty shale and cemented sandstone.

Density: Siltstone-shale: very low to medium (60 to 90 pcf); sandstone: medium (100 to 150 pcf).

Expansibility: Siltstone and shale weather to plastic clays which are very expansive.

Structural fabric: Very developed due to thin, fissile bedding and bentonitic layers commonly closely jointed and fractured in the weathered zone.

Erodibility: Siltstone and shale erode easily when weathered, but only moderately when fresh; cherty shale forms large irregular blocks along northwest seacoast.

Other: Siltstone and shale are commonly deeply weathered. Excavations suggest weathered zone is commonly 50 feet thick.

USE POTENTIAL

Sand and gravel: None. Cemented sandstone and cherty shale might be used as small riprap, but quantity available appears small.

Fill: Poor to fair for impervious fill. Low compactability. Expansive.

Waste disposal sites: Good in some areas due to ease of excavation, low permeability and many landslides. Poor, over-all, because most areas are too near the seacoast and on the coastal side of the divide.

Aquifer: Poor.

Other: Low density siltstone and shale may have use as expanded aggregate or absorbent. Local phosphate nodules and thin oolitic shales suggest the possibility of economic phosphate deposits.

SAN ONOFRE BRECCIA (Tso and Tso–ss)

TERRAIN FEATURES

Topographic expression: Moderate to steep slopes with rounded hilltops and rounded, narrow steep-sided ridge tops commonly paralleling strike of beds.

Vegetation: Moderate to dense brush; grass and scattered brush on siltstone.

Approximate natural slope angle range: 15° to 40°; some scarps and incised drainage slopes exceed 60°.

Slope-wash development: Thin to nonexistent, except moderately thick and expansive in areas of siltstone.

Soil development: Thin on most slopes; moderately thick and expansive on gentle slopes developed in siltstone.

LITHOLOGIC FEATURES

Type and color: Marine; locally nonmarine(?) reddish-brown, yellowish-brown, greenish-gray and bluish-gray breccia; conglomerate; sandstone (Tso–ss) and siltstone; matrices range from coarse sand to clay.

Bedding: Massive to poorly bedded, commonly lenticular with gross variations in structure and material over relatively short distances.

Induration: Moderately well-indurated and cemented; local variations including poorly cemented, especially in deeply weathered areas and in siltstone.

Angularity: Mostly angular to subangular boulders, subangular to subrounded cobbles, subangular to rounded pebbles, and angular to subrounded sand.

Sorting: Mostly very poor with minor areas of fair to good sorting.

Composition: Clasts are quartzite, quartz schist (containing lawsonite and muscovite), albite schist (containing chlorite and muscovite), epidote-amphibole schist, blue-green schist (containing glaucophane actinolite, muscovite, lawsonite, serpentine), and saussuritized gabbro. Matrix is quartz, feldspar, clay minerals, and lithic grains.

Structure: Complex, with gentle to steep bedding; faulting seems predominant.

Thickness: Perhaps up to 3000 feet in southern part of the quadrangle; between 500 and 1000 feet in Boat Canyon-Emerald Bay area. Presumably lenses out in northwest direction along the Pelican Hill fault zone (Vedder, 1971, p. 13 and 14).

Contact relations: Generally unconformable on Topanga Formation locally, with channeling into Topanga Formation. But, in places, conformably gradational on Tt and locally interbedded with Los Trancos Member along Pelican Hill fault zone.

Age and fossils: Locally contains middle Miocene marine fossils, including *Balanus, Lyropecten crassicardo, Pecten (Amusium) lompocensis* Arnold, and in the upper part of the section, *Vaquerosella andersoni* (Morton *et al.*, 1974).

ENGINEERING FEATURES

Unified soil classification: GC, GM, SC, SM, CL when disaggregated.

Workability: Workable with some difficulty with heavy power equipment; locally requires blasting, especially of large unweathered boulders in small or narrow excavations; commonly, selective disposal of large boulders and cobbles is required.

Slope stability: Generally good, but fair to poor in local siltstone, shale, and sheared zones along major faults; bedding orientation is seldom a strong factor in slope stability of sound breccia and conglomerate facies. Tso (breccia facies) is one of the most stable rock units within the quadrangle.

Permeability: Medium to low; especially low where clayey matrix is prevalent.

Porosity: Low to medium; high in shale and siltstone.

Density: Relatively high; commonly exceeds 150 pcf dry density.

Expansibility: Low in sandy matrix facies. Moderate in clayey matrix and siltstone facies.

Structural fabric: Minimal. Reacts massively due to lack of distinct planar structures except for zones, in siltstone especially, and facies with clayey matrix.

Erodibility: Low, especially in fresh rock, but locally moderate in deeply weathered zones, especially in siltstone and facies with clayey matrix.

USE POTENTIAL

Sand and gravel: None; too variable with excessive fines.
Fill: Fair to good for fill except for larger-sized clasts and expansive nature of clayey matrix and siltstone facies.
Waste disposal sites: Generally poor, due to rather limited areal extent, proximity to major drainages, and somewhat difficult grading properties.
Aquifer: Poor, due to lenticularity of beds and generally low permeability.
Other: Large boulders make excellent decorative landscaping stone.

TOPANGA FORMATION (Undifferentiated) (Tt)

TERRAIN FEATURES

Topographic expression: Moderate to steep slopes with narrow steepsided ridge tops commonly paralleling strike of beds; gentle to moderate slopes in predominantly siltstone areas.
Vegetation: Moderate to sparse brush and light to moderate chaparral. Some oak woodlands, especially in sheltered canyons; barren on steep, well-cemented sandstone; grass with light brush on siltstone facies.
Approximate natural slope angle range: 15° to 40°+; some scarps and steeply incised drainage slopes; thick, well-cemented sandstone outcrops are nearly vertical for 40 or more feet.
Slope-wash development: Thin to sparse in sandstone; thick and expansive in areas of siltstone and thick, loose, fine, silty sand along base of slopes.
Soil development: Generally thin and poorly developed, except on gentle slopes in areas of siltstone where soil is moderately thick and expansive.

LITHOLOGIC FEATURES

Type and color: Marine; yellowish-gray, dusky yellow, pale yellowish-brown, moderate yellowish-brown, light brown to light olive-gray fine silty sandstone, locally conglomeratic, and interbedded brownish and olive-gray siltstone.
Bedding: Thickly bedded, often broadly lenticular, locally medium- to thin-bedded.
Induration: Moderately well indurated. Well cemented sandstone predominates with friable sandstone and soft siltstone interbeds.
Angularity: Mostly subangular to subrounded grains with minor subrounded to rounded pebbles and very minor subangular to subrounded cobbles.
Sorting: Moderately well to well (poorly graded).
Composition: Quartz, feldspar, clay minerals and lithic grains of mainly quartzite and schist with minor hornblende and mica; pebbles are mostly acidic volcanic and plutonic varieties; minor cobbles are commonly glauc-amphibole varieties.
Structure: Generally moderately steep; easterly dips north of the Temple Hills fault; gentle to steep southerly dips south of the Temple Hills fault.
Thickness: As much as 3500 feet thick (Vedder, 1970, p. 17).
Contact relations: Probably conformable contact with the underlying Vaqueros Formation; interfingered and gradational with the overlying San Onofre Breccia southwest of Laguna Canyon fault, but generally unconformable with Tso northeast of Laguna Canyon fault.
Age and fossils: Contains abundant middle Miocene marine fauna including *Balanus, Lyropecten crassicardo, Turritella ocoyana topangaensis, Ostrea titan, Pecten (Amusium) lompocensis* Arnold, and *Pecten vanvlecki* Arnold. (Morton *et al.*, 1974).

ENGINEERING FEATURES

Unified soil classification: SM, ML, CL with minor GM when disaggregated.
Workability: Commonly workable with power equipment with minor to some difficulty; locally may require blasting in well-cemented sandstone beds.
Slope stability: Generally good, except in siltstone or interbedded siltstone and friable sandstone beds where slumping and bedding plane slides are common. Rockfall and rock glide are common on steep slopes of resistant sandstone.
Permeability: Medium to low due to appreciable percentage of fines, siltstone interbeds, and well-cemented beds.

Porosity: Medium in sandstone to relatively high in siltstone.
Density: Moderate; most sandstone ranges from 120 to 150 pcf dry density; most siltstone ranges from 85 to 100 pcf dry density.
Expansibility: Low to nonexpansive in most sandstone; low to moderate in most siltstone.
Structural fabric: Minimal to moderate due to generally massive, thick bedding and broadly lenticular zones; locally sheared, jointed and thin-bedded.
Erodibility: Low in well cemented sandstone; moderate in friable sandstone and siltstone.

USE POTENTIAL

Sand and gravel: Low.
Fill: Good for fill except for rilling tendencies in sand, expansive character of siltstone-derived material, and rather difficult workability.
Waste disposal sites: Fair to poor due to difficult workability, moderate permeability, and proximity to major drainages.
Aquifer: Fair to poor due to appreciable fines and lenticularity of beds with interbedded siltstone and well-cemented sandstone of low permeability.

PAULARINO MEMBER, TOPANGA FORMATION (Ttp)

TERRAIN FEATURES

Topographic expression: Ttp occurs in a 5 acre area along the Big Canyon. Because of extensive urban development in this area, it has not been thoroughly studied for this report.
Vegetation: Grass, very light brush, and chaparral.
Approximate natural slope angle range: 5° to 30°.
Slope-wash development: Generally absent; usually covered by slope-wash derived from overlying Qtn.
Soil development: Absent to thin.

LITHOLOGIC FEATURES

Type and color: Marine sandstone, siltstone, and some shale, and possibly nonmarine breccia and flows. Light gray, yellowish-gray and light olive-gray tuffaceous fine to coarse-grained sandstone, siltstone and shale. Dark- to medium-gray, brownish-black, and grayish-brown sedimentary breccia, andesite flows, and flow breccia.
Bedding: Massive to moderately bedded sandstone and siltstone, and some well-bedded shale and siltstone.
Induration: Moderately indurated. Some sandstones and most shale and siltstone become soft when saturated.
Angularity: Sandstone: subrounded to subangular.
Sorting: Moderately to poorly sorted sandstone.
Composition: Tuffaceous quartzo-feldspathic sandstone and siltstone with biotite and montmorillonite clay.
Structure: Monoclinally and moderately dipping to the northeast.
Thickness: 1275 to 1500 feet (Vedder *et al.*, 1957; Vedder, 1970, p. 17).
Contact relations: Ttp is in fault contact with the older Monterey Formation and unconformably overlain by marine terrace deposits (Qtn).
Age and fossils: *Siphogenerina* cf *hughesi* and *Valvulineria californica* (Vedder *et al.*, 1957) indicating middle Miocene age.

ENGINEERING FEATURES

Unified soil classification: Sandstone: SC, SM. Siltstone and shale: ML, CL, MH.
Workability: Moderate; however locally well-cemented resistant sandstone may pose some difficulties.
Slope stability: Moderate.
Permeability: Moderately low due to induration of sandstone and moderate silt and clay content.
Porosity: Moderately low to moderate.
Density: Moderate; sandstone: 120 to 150 pcf; siltstone and shale: 80 to 100 pcf.
Expansibility: Low in general; moderate where underlain by shale and siltstone.

Structural fabric: Moderately well to moderate. Massive to thickly bedded sandstone and siltstone; thinly bedded shale and siltstone.
Erodibility: Moderately low due to moderate induration.

USE POTENTIAL

Sand and gravel: None, due to restricted areal extent, excessive fines, and little or no gravel fraction.
Fill: Generally well suited for fill.
Waste disposal sites: None, due to limited extent.
Aquifer: None, due to moderately low permeability and limited extent.

TOPANGA FORMATION LOS TRANCOS MEMBER (Ttl)

TERRAIN FEATURES

Topographic expression: Gently to steeply rounded slopes.
Vegetation: Grass, with light to moderate chaparral and brush.
Approximate natural slope angle range: 10° to 40°.
Slope-wash development: Generally moderately thick.
Soil development: Generally moderately thick and expansive, particularly on gentle northerly and easterly facing slopes.

LITHOLOGIC FEATURES

Type and color: Marine; medium- to dark-gray, yellowish-gray, moderate yellowish-brown, light-brownish to light olive-gray siltstone, and fine-grained sandstone with interbedded medium- to coarse-grained sandstone and shale; locally tuffaceous sandstone.
Bedding: Thin to medium bedded siltstone; locally thick-bedded sandstone.
Induration: Moderate; relatively soft siltstone is predominant with resistant sandstone interbeds.
Angularity: Mostly subangular to subrounded sand grains.
Sorting: Moderately well sorted.
Composition: Quartz, feldspar, clay minerals, and lithic grains of quartzite, schist, and volcanic and plutonic varieties; sandstones are locally tuffaceous.
Structure: Moderately steep northwesterly dips, with complex structure along the Pelican Hill fault zone.
Thickness: Maximum thickness of 3100 feet is estimated in the Coyote Canyon area (Vedder, 1970, p. 8 and 17).
Contact relations: Gradational conformable contact with the underlying Bommer Member. Unconformable, but locally interfingered and gradational with overlying San Onofre Breccia.
Age and fossils: Middle Miocene, *Valvulineria depressa, Bolivina advena* var. *Baggina cancriformis* (Vedder *et al.*, 1957; Kleinpell, 1938).

ENGINEERING FEATURES

Unified soil classification: ML, CL, SM, SC.
Workability: Easily graded by power equipment.
Slope stability: Poor to fair. Ttl is one of the most landslide-prone bedrock units within the quadrangle.
Permeability: Medium to low.
Porosity: Medium to high.
Density: Moderate; most siltstone ranges from 85 to 100 pcf dry density, and most sandstone 120 to 150 pcf.
Expansibility: Moderate to low in siltstones, low to nonexpansive in most sandstone.
Structural fabric: Generally thin to medium bedded, locally sheared and jointed.
Erodibility: Moderate to high in siltstone, low in resistant sandstone.

USE POTENTIAL

Sand and gravel: Low.
Fill: Fair to poor due to expansive character of some of the siltstone-derived material.

Waste disposal sites: Generally good due to easy workability, low- to medium-permeability, etc. The present Orange County Sanitary Landfill, Coyote Canyon, is located entirely in Ttl; no major problem has been encountered.

Aquifer: Fair to poor, due to medium to low permeability and lenticularity of beds.

TOPANGA FORMATION BOMMER MEMBER (Ttb)

TERRAIN FEATURES

Topographic expression: Moderate to steep slopes with narrow, steepsided ridge tops commonly paralleling strike of beds; gentle to moderate slopes in predominantly siltstone areas.

Vegetation: Moderate to sparse brush and light to moderate-chaparral. Some oak woodlands, especially in sheltered canyons. Barren on steep, well-cemented sandstone; grass with light brush on siltstone facies.

Approximate natural slope angle range: 15° to 40°; some scarps and steeply incised drainage slopes; thick well-cemented sandstone outcrops are nearly vertical for 40 or more feet.

Slope-wash development: Thin to sparse in sandstone; thick and expansive in areas of siltstone, and thick, loose, fine silty sand along base of slopes.

Soil development: Generally thin and poorly developed, except on gentle slopes in areas of siltstone where soil is moderately thick and expansive.

LITHOLOGIC FEATURES

Type and color: Marine; yellowish-gray, dusky-yellow, pale yellowish-brown, moderate yellowish-brown, light brownish to light olive-gray, medium-fine to coarse-grained sandstone, locally conglomeratic, and interbedded brownish and olive-gray siltstone and fine-grained sandstone.

Bedding: Thickly bedded, commonly broadly lenticular, locally medium- to thinly-bedded.

Induration: Moderately well indurated. Well-cemented sandstone predominates with friable sandstone and soft siltstone interbeds.

Angularity: Mostly subangular to subrounded grains with minor subrounded to rounded pebbles and very minor subangular to subrounded cobbles.

Sorting: Moderately well to well sorted; poorly graded.

Composition: Quartz, feldspar; clay minerals and lithic grains of mainly eastern bedrock complex; pebbles are mostly acidic volcanic and plutonic varieties.

Structure: The regional relative arrangement of attitude of bedding shows a northerly plunging "anticlinal" structure which is created by faulting rather than folding. Fault blocks have homoclinal structures with moderately dipping beds.

Thickness: About 2400 feet (Vedder, 1970, p. 16).

Contact relations: Gradational conformable contact with the underlying Vaqueros Formation; locally interfingered and gradational with the overlying Los Trancos Member.

Age and fossils: Contains abundant middle Miocene marine fauna including *Balanus, Lyropecten crassicardo, Turritella ocoyana topangaensis, Turritella temblorensis, Ostrea titan, Pecten (Amusium) lompocensis* Arnold, and *Pecten vanvlecki* Arnold (Morton *et al.*,1974; Vedder *et al.*, 1957; Vedder, 1970, p. 9).

ENGINEERING FEATURES

Unified soil classification: SM, ML, CL, with minor GM when disaggregated.

Workability: Commonly workable with power equipment with minor difficulty; locally requires minor blasting in well-cemented beds, especially in small or narrow excavations. Resistant sandstone outcrops interpreted from aerial photographs are plotted on map as dashed-dotted lines.

Slope stability: Generally good, except in siltstone or interbedded siltstone and friable sandstone beds where slumping and bedding plane slides are fairly common. Rockfall hazard in steep areas of hard sandstone.

Permeability: Medium to low, due to appreciable percentage of fines, siltstone interbeds, and well-cemented beds.

Porosity: Medium in sandstone to relatively high in siltstone.

Density: Moderate; most sandstone ranges from 120 to 150 pcf dry density; most siltstone ranges from 85 to 100 pcf dry density.

Expansibility: Low to nonexpansive in most sandstone; low to moderate in most siltstone.

Structural fabric: Minimal to moderate due to generally massive and thick bedding and broadly lenticular zones; locally sheared and jointed.
Erodibility: Low in well-cemented sandstone; moderate in friable sandstone and siltstone.

USE POTENTIAL

Sand and gravel: Low; silty fine sand plentiful, but very little gravel.
Fill: Good for fill except for the hard sandstone beds and expansive character of siltstone-derived material. Resistant sandstone can be used as riprap.
Waste disposal sites: Generally poor, due to difficult workability, high permeability of fill derived from sandstone, and proximity of Topanga terrain to major drainages.
Aquifer: Poor, due to appreciable fines and lenticularity of beds with interbedded siltstone of low permeability.

VAQUEROS FORMATION (Tv)

TERRAIN FEATURES

Topographic expression: Rounded hills with relatively steep antidip slopes.
Vegetation: Brush, normally with chaparral on steep slopes and in canyons.
Approximate natural slope angle range: 5° to 40°, highly variable, reflecting variable composition; locally along major canyons; antidip slopes may be as steep as 45°.
Slope-wash development: Generally, poorly developed except on silty or shaly horizons where commonly it is expansive and more than 3 feet thick.
Soil development: Usually less than 2 feet thick except on silty or shaly horizons where commonly it exceeds 3 feet of expansive soil. Sandy loam to loam.

LITHOLOGIC FEATURES

Type and color: Marine, pale yellow-brown to dusky yellowish-green, silty fine- to medium-grained arkosic sandstone with siltstone and shale interbeds. Well-indurated, calcareously cemented coarse-grained sandstones occur locally west of the Laguna Canyon Road.
Bedding: Massive to thick bedded, but with local abundant thin-bedded silty and shaly horizons.
Induration: Moderate to well indurated. Calcareous sandstone very well indurated.
Angularity: Subangular and subrounded.
Sorting: Predominantly poorly sorted with well-sorted interbeds.
Composition: Arkosic sandstones derived from tonalite, siliceous metavolcanic and metasedimentary rocks of the Santa Ana Mountains, eastern bedrock complex (Woodford, 1925).
Structure: Faulted blocks commonly dip homoclinally towards the east in the area west of Laguna Canyon and other faulted blocks dip in various directions.
Thickness: Ranges from 2700 to 3750 feet (Vedder, 1970); at least 2000 feet within the quadrangle.
Contact relations: Gradational, conformable contact with the underlying Sespe Formation and overlying Topanga Formation.
Age and fossils: Contains abundant early Miocene shallow water marine fauna including *Turritella inezana* Conrad, *Rapana vaquerosensis* Arnold *imperialis* Hertlein and Jordon, *Balanus,* and *Ostrea* (Morton *et al.*, 1974).

ENGINEERING FEATURES

Unified soil classification: Principally SM, SC and SW with ML and CL common in silty and shaly horizons (disaggregated).
Workability: Easily excavated with power equipment. Local calcareously cemented sandstones and coquina may require blasting. Resistant sandstone outcrops, interpreted from aerial photographs, are plotted on map as dashed-dotted lines.
Slope stability: Generally poor to very poor in shaly or silty horizons, particularly where beds are daylighted. Tv is one of the most landslide-prone bedrock units within the quadrangle.
Permeability: Moderate to low except for several highly permeable sandstones.
Porosity: Moderate to low.
Density: Moderately dense (90 to 120 pcf) for sedimentary rocks.

Expansibility: Moderate to high in the weathered zone of shaly and silty horizons.
Structural fabric: Massive to thick bedded except for thin, well-bedded shaly and silty horizons.
Erodibility: Generally moderate, but low for some resistant sandstones.

USE POTENTIAL

Sand and gravel: Low; sands contain significant percentages of fines and only minor gravel.
Fill: Suitable for pervious or impervious fill depending on horizon being considered, except for calcareous sandstone which can be used as riprap but is limited in extent.
Waste disposal sites: Fair to good; easy workability, generally low permeability; many landslides, large areal extent, little to no development.
Aquifer: Poor, due to generally low permeability and lenticularity of beds.

SESPE FORMATION (Ts)

TERRAIN FEATURES

Topographic expression: Resistant sandstones or conglomeratic sandstones commonly form steep slopes. Less resistant rocks form low, rounded hills.
Vegetation: Brush and cactus with interspersed grassy areas.
Approximate natural slope angle range: 10° to 40°.
Slope-wash development: Commonly thick; 3 to 10 feet accumulations of highly plastic reddish sandy clay on lower slopes and in canyon bottoms.
Soil development: Thin; less than 1 foot on resistant sandstones and upper slopes; however, on gentle slopes it commonly exceeds 3 feet of highly plastic reddish-brown sandy clay (clay loam).

LITHOLOGIC FEATURES

Type and color: Nonmarine, moderate red to very pale orange, medium- to coarse-grained clayey and silty arkosic sandstone with minor beds of conglomeratic sandstone, conglomerate, and mudstone.
Bedding: Thick, poorly bedded and commonly crossbedded.
Induration: Moderate to well.
Angularity: Subangular to well rounded.
Sorting: Poor.
Composition: Conglomerates commonly contain dark, multicolored siliceous porphyry and welded tuffs. The sandstone and matrix of conglomerates contain quartzo-feldspathic sand and silt with minor amounts of red clay.
Structure: Generally dips homoclinally east.
Thickness: Maximum thickness in the San Joaquin Hills is about 2500 feet (Yerkes *et al.*, 1960). Exposures in the northeast corner of quadrangle are estimated to be at least 1000 feet thick.
Contact relations: A gradational (conformable) contact with the underlying Santiago Formation and overlying Vaqueros Formation.
Age and fossils: Late Eocene(?) to early Miocene (Yerkes *et al.*, 1968). This is based primarily on marine mollusks underlying and overlying the Sespe Formation (Morton *et al.*, 1974).

ENGINEERING FEATURES

Unified soil classification: Principally SM and SC, commonly with beds of SW, SP, and GC (disaggregated).
Workability: Generally easily removed with power equipment when moist. Heavy-duty rippers and blasting may be required for resistant sandstone and conglomeratic sandstone beds.
Slope stability: Generally fair to good, but commonly poor in clayey and silty horizons.
Permeability: Low to moderate, with local horizons of low permeability.
Porosity: Moderate.
Density: Moderate (90 to 120 pcf).
Expansibility: Probably low in fresh unsheared rock; however, much of the formation is extensively sheared and weathered and thus tends to be expansive. Slope wash and soil seem expansive, too.
Structural fabric: Commonly complexly fractured and sheared; slickensides common in most fine-grained beds; limy coatings common along shears or fractured surfaces.
Erodibility: Low to moderate.

USE POTENTIAL

Sand and gravel: Low because of plastic fines and generally low gravel content.
Fill: Good except for expansive slope wash and soil.
Waste disposal sites: Good to fair; easy workability, moderate permeability.
Aquifer: Moderate to poor.
Other: Potential petroleum reservoir rock.

SANTIAGO FORMATION (Tsa)

TERRAIN FEATURES

Topographic expression: The unit forms part of a moderately steep slope covering a small area of about 1½ acres within the quadrangle.
Vegetation: Moderate to light brush and chaparral.
Approximate natural slope angle range: 10° to 30°.
Slope-wash development: Generally thin to sparse.
Soil development: Generally thin and poorly developed.

LITHOLOGIC FEATURES

Type and color: Marine and nonmarine(?) greenish-gray, yellowish-gray and moderate to pale yellowish-brown, medium- to coarse-grained sandstone with interbedded moderate reddish-brown and grayish-green fine-grained clayey sandstone.
Bedding: Thick bedded to massive coarse-grained sandstone and thin-bedded fine-grained sandstone.
Induration: Moderate to well indurated; coarse-grained sandstones are more resistant than the fine grained ones.
Angularity: Angular to subrounded sand grains.
Sorting: Moderately well.
Composition: Quartz, feldspar, clay minerals, and lithic grains of eastern bedrock complex source.
Structure: Faulted against the younger Sespe Formation; moderately steep dip to the west and southwest.
Thickness: Possibly less than 600 feet of the lower part of Tsa is exposed.
Contact relations: Gradational contact with the underlying Silverado Formation; however, this contact is described as an unconformity in other areas of Orange County (Woodring *et al.*, 1945; Morton, 1970, 1974). Fault contact with the younger Sespe Formation.
Age and fossils: Eocene (Vedder *et al.*, 1957; Vedder, 1970, p. 16). The limited occurrence of Tsa in this area has been queried on the accompanying map because it may be the upper part of Tsi.

ENGINEERING FEATURES

Unified soil classification: SM, ML, CL with some SC.
Workability: Commonly, workable with difficulty due to resistant, coarse-grained sandstone.
Slope stability: Generally good, some minor rockfall on steep slopes of resistant sandstone.
Permeability: Medium to moderately low.
Porosity: Medium.
Density: Moderate, 100 to 150 pcf.
Expansibility: Low (finer-grained sandstone) to nonexpansive (coarse-grained sandstone).
Structural fabric: Minimal to moderate due to massive and thick bedding; locally sheared, jointed, and thin-bedded.
Erodibility: Generally low; higher in fine-grained sandstone interbeds.

USE POTENTIAL

Sand and gravel: Low.
Fill: Good for fill except for rilling tendencies in sand.
Waste disposal sites: Poor. Moderate permeability, limited areal extent and proximity to major drainage (Shady Canyon).
Aquifer: Fair to poor; moderate permeability but very limited extent.

SILVERADO FORMATION (Tsi)

TERRAIN FEATURES

Topographic expression: Gentle to steep slopes with large blocks of hard sandstone.
Vegetation: Moderate to light brush on steep slopes and chaparral and some grass and trees on gentler slopes.
Approximate natural slope angle range: 10° to 35°; variable, reflecting variable composition.
Slope-wash development: Generally poorly developed.
Soil development: Generally poorly developed on steeper slopes; 20 to 40 inches of sandy loam on moderate slopes.

LITHOLOGIC FEATURES

Type and color: Marine and nonmarine, pale yellowish-brown, light brown, grayish-olive medium to coarse grained sandstone and some interbeds of conglomeratic sandstone and sandy clay and claystone (clay bed indicated on the map by dashed line within formation).
Bedding: Thickly bedded, commonly broadly lenticular, locally medium to thinly bedded.
Induration: Generally, moderately well indurated; locally very hard, siliceous cementation.
Angularity: Mostly subangular to subrounded sand grains; subrounded to rounded pebbles.
Sorting: Moderately well.
Composition: Quartz, feldspar, clay minerals (kaolinite) and lithic grains, from eastern bedrock complex.
Structure: Faulted blocks, commonly dipping homoclinally to the west-southwest and to the south in the smaller, southern fault block.
Thickness: Approximately 1875 feet thick (Vedder, 1970, p. 16).
Contact relations: The lower contact is not exposed in the quadrangle. It seems to have a gradational contact with the overlying Santiago Formation; however, the contact is described as an unconformity in other areas of Orange County (Woodring *et al.*, 1945; Morton, 1970, 1974).
Age and fossil: Paleocene (Vedder *et al.*, 1957; Vedder, 1970, p. 16).

ENGINEERING FEATURES

Unified soil classification: SM, ML, CL with some SC and SM (if disaggregated).
Workability: Commonly, workable with difficulty due to resistant sandstone beds which are plotted on the map as dashed-dotted lines, as interpreted from aerial photographs.
Slope stability: Generally good, some rockfall on steep slopes of resistant sandstone.
Permeability: Moderately light to medium; low in claystone.
Porosity: Medium; higher in claystone.
Density: Moderate, 100 to 150 pcf; lower densities in sandy clay (80 to 100 pcf).
Expansibility: Low to nonexpansive; the sandy clays do not show expansive features.
Structural fabric: Minimal to moderate due to massive and thick bedding; locally sheared; jointed and thin bedded.
Erodibility: Generally, low to moderate.

USE POTENTIAL

Sand and gravel: Low.
Fill: Good for fill except for the hard sandstones which can be used for riprap.
Waste disposal sites: Poor, due to moderately high permeability, locally difficult workability, and proximity to a major drainage (Shady Canyon).
Aquifer: Low.
Other: The ceramic clay and sand in the Silverado Formation are mined in Orange County. No investigation or analysis of the 10 to 30 feet thick clay beds within the quadrangle was made. Due to their limited extent, commercial potential is doubtful. The clay bed dip-slopes and is near the surface. It is located in a 15-acre area on the eastern side of the northernmost part of Shady Canyon, within the quadrangle.

ANDESITE INTRUSIONS (Ta)

TERRAIN FEATURES

Topographic expression: Moderately steep slopes inland, but forms very steep resistant sea cliffs.
Vegetation: Grass with light brush and chaparral; barren on sea cliff faces.
Approximate natural slope angle range: 10° to 30° inland; up to 80° on sea cliffs.
Slope-wash development: Generally thin.
Soil development: Generally thin to moderate, none on sea cliffs and steep slopes.

LITHOLOGIC FEATURES

Type and color: Medium light- to dark-gray if unweathered, light brownish-gray, light brown, pale to moderate yellowish-brown, grayish-orange and dark yellowish-orange if weathered.
Bedding: None.
Induration: Very hard and resistant except where weathered.
Angularity: —
Sorting: —
Composition: Fine-grained basic volcanic rock composed principally of plagioclase and augite.
Structure: Generally vertical to subvertical dikes and plugs of irregular form.
Thickness: Variable, ranging from several inches to several hundred feet. About 500 feet wide east of El Morro School and between Twin Points and Recreation Point; 1500 feet wide at Two Rock Point. At Abalone Point and southeast of it, it may have the irregular configuration of an intrusive plug.
Contact relations: Shallow intrusives into and along fractures, faults, and bedding; some minor baking effects of adjacent sediments.
Age and fossils: Post upper Miocene Monterey Formation, probably of late Miocene age (Vedder *et al.*, 1957).

ENGINEERING FEATURES

Unified soil classification: —
Workability: Generally very difficult, due to resistant nature of rock. Fairly easy in weathered rock.
Slope stability: Good except for locally intensely weathered rock. Rockfalls frequently occur on steep slopes underlain by hard andesite.
Permeability: Generally low; joints, fractures, and weathering increase permeability.
Porosity: Low.
Density: Moderate (160 to 180 pcf), lower densities in weathered rocks.
Expansibility: Low to nonexpansive.
Structural fabric: Commonly jointed and fractured, locally sheared.
Erodibility: Moderate to low.

USE POTENTIAL

Sand and gravel: None.
Fill: Poor due to hard rock.
Waste disposal sites: Poor due to very difficult workability and limited extent.
Aquifer: Poor due to low permeability and limited extent.

DIABASE INTRUSIONS (Td)

TERRAIN FEATURES

Topographic expression: Variable depending on surroundings due to limited areal extent. Td is usually less resistant than surroundings and forms lower areas, particularly in the sandstones of Ttb, Tv, Ts and Tsi. Larger areas of Td within Ttl have the same topographic expression as the Ttl terrain.
Vegetation: Variable, depending on surroundings. Larger areas are generally covered by grass and light to moderate brush and chaparral.
Approximate natural slope angle range: 10° to 40°; variable, depending on surrounding.
Slope-wash development: Generally thin due to limited areal extent.
Soil development: Generally moderately thick due to severe weathering of the diabase.

LITHOLOGIC FEATURES

Type and color: Dikes and sills; dark- to medium-gray, olive-gray and dark greenish-gray if fresh; pale, light- to moderate-brown, pale to moderate yellowish-brown, light olive-gray, and grayish-olive if weathered.
Bedding: None.
Induration: Generally soft and friable due to deep weathering; hard and resistant if fresh.
Angularity: —
Sorting: —
Composition: Medium- to coarse-grained basic volcanic rock composed principally of plagioclase and augite.
Structure: Vertical and subvertical dikes and moderately steep dipping sills (northwesterly dip in the San Joaquin Reservoir and Coyote Canyon Sanitary Landfill area).
Thickness: Variable, ranging from several inches to several tens of feet; thickest dike, in the northeastern corner of the quadrangle, is about 400 feet thick. The largest sills located in the San Joaquin Reservoir area may be less than 25 feet thick.
Contact relations: Shallow intrusives generally intruded along faults but also fractures and beddings; some local minor baking effects.
Age and fossils: Post middle Miocene Topanga Formation. Probably of middle Miocene age (Vedder *et al.*, 1957).

ENGINEERING FEATURES

Unified soil classification: Deeply weathered materials are mainly SC, SM, ML, and CL.
Workability: Easy workability, local unweathered diabase may need blasting.
Slope stability: Fair to good, local thick soil on slopes may be subject to creep and erosion.
Permeability: Low in weathered diabase, almost none in unweathered rock. Some permeability due to joints, shears, and fractures.
Porosity: Low; higher in weathered rocks than in unweathered rocks.
Density: Moderate; lower densities in weathered rocks.
Expansibility: Low to nonexpansive; soil may be slightly expansive.
Structural fabric: Commonly jointed and fractured, locally sheared.
Erodibility: Moderate in weathered diabase, low in unweathered diabase.

USE POTENTIAL

Sand and gravel: None.
Fill: Fair in weathered diabase.
Waste disposal sites: Poor, due to limited extent.
Aquifer: Poor, due to low permeability and limited extent.

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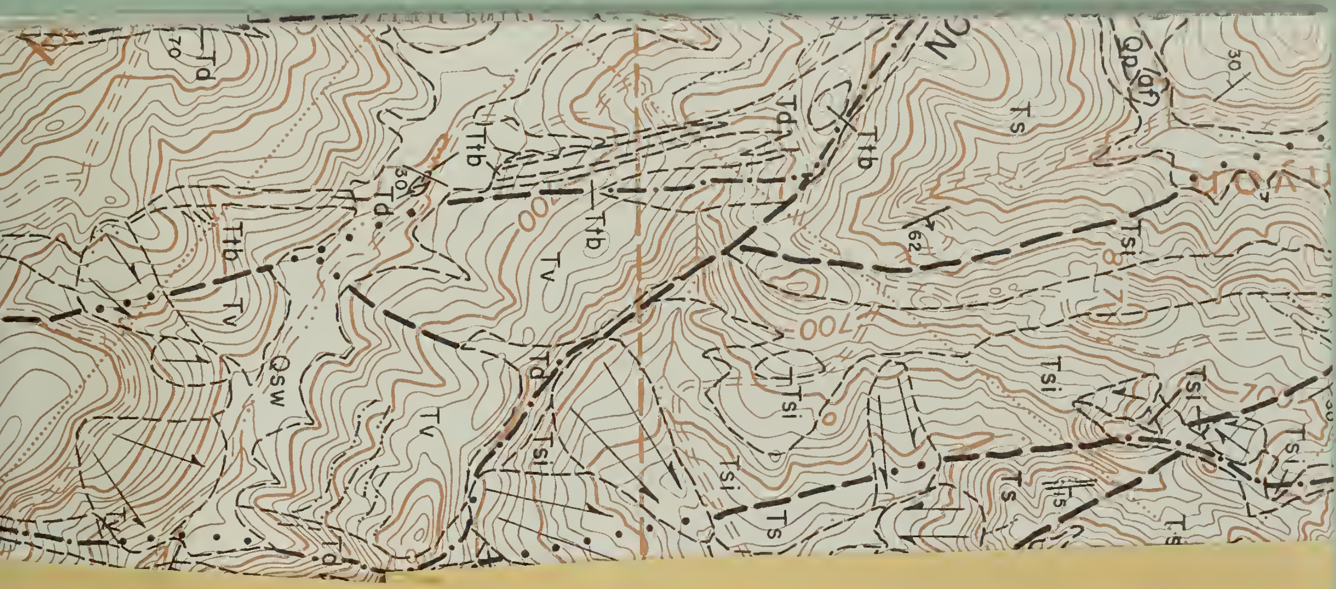

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LAGUNA BEACH QUADRANGLE
SPECIAL REPORT 127, PLATE 1

SURFICIAL UNITS *

QUATERNARY

Holocene

af	Artificial fill and cut areas (shown superimposed over rock units) af = mappable artificial fill
Qal	Alluvium
Qp	Pond deposit
Qsw	Slopewash debris
Qb	Beach sediments; Qbs - mainly sand; Qbg - mainly gravel, Qbs+g - mainly sand & gravel
	Landslide debris

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SURFICIAL UNITS *

Age	Symbol	Description
QUATERNARY, Holocene	af	Artificial fill and cut areas (shown superimposed over rock units) af=mappable artificial fill
	Qal	Alluvium
	Qp	Pond deposit
	Qsw	Slopewash debris
	Qb	Beach sediments, Qbs - mainly sand; Qbg - mainly gravel, Qbs+g - mainly sand & gravel
		Landslide debris
Pleistocene	Qt	Stream terrace deposits
	Qln	Nonmarine deposits on marine terrace deposits (subscripts indicate relative level with 1 the lowest)
	Qlm	Marine terrace deposits (without nonmarine cover)

BEDROCK UNITS *

Age	Symbol	Description
TERTIARY, Pliocene	Tc	Capistrano Formation
Miocene	Tm	Monterey Formation, Tm-ss - sandstone
	Tso	San Onofre Breccia, Tso-ss - sandstone
	Tt: Ttp, Ttl, Ttb	Topanga Formation, Ttp - Paularino member, Ttl - Los Trancos member, Ttb - Bommer member
Oligocene	Tv	Vaqueros Formation
	Ts	Sespe Formation
Eocene	Tsa	Santiago Formation
Paleocene	Tsi	Silverado Formation

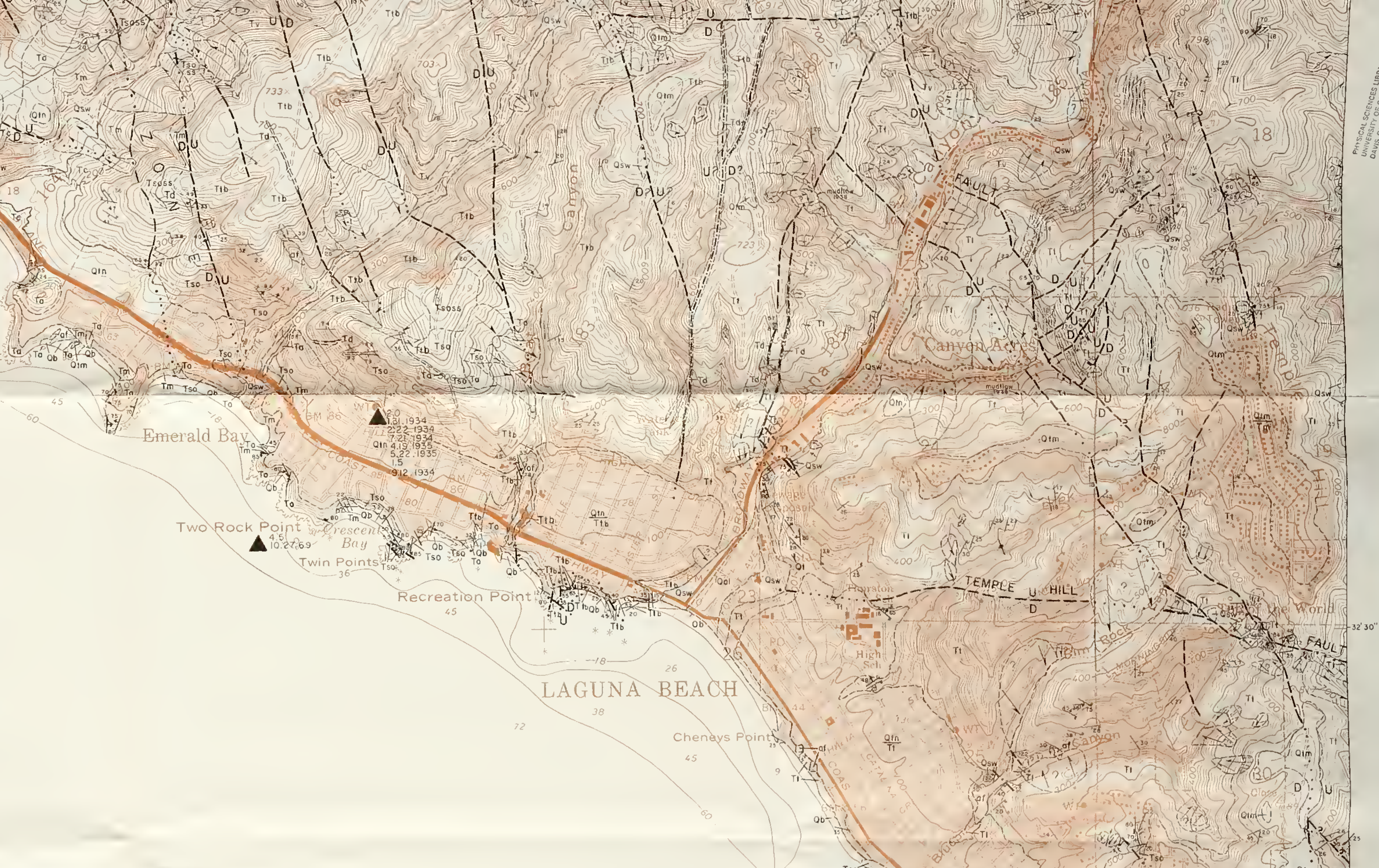
Intrusive Rocks *

Age	Symbol	Description
Upper Miocene	Ta	Andesite intrusions and dikes
Middle Miocene	Td	Diabase sills and dikes

* See text for detailed descriptions.

SYMBOLS

Symbol	Explanation
?–?	Contacts, dotted where concealed, dashed where approximated, queried where inferred, solid where located with certainty
clay bed	Bed of clay (within Silverado Formation)
	Resistant sandstone outcrops plotted from aerial photographs
75 35 U D	Faults dotted where concealed; dashed where approximated, queried where inferred, solid where certain, arrows show direction and numbers show amount of dip of fault plane and fault striations, U=upblock relative to downblock - D
Td	Fault intruded by dike (Td), no known post-dike movement
24	Attitude of bedding
24 E	Attitude of bedding taken from excavation
	Vertical bedding
78	Attitude of shear surface
78 E	Attitude of shear surface taken from excavation
	Vertical shear surface
80	Attitude of joint surface
	Axis of synclinal fold
Qlm / Tt	Developed area of artificial cut and fill with surficial unit thinly overlying bedrock unit
	Bedrock landslide, arrows indicate direction of failure; scarp hachured where apparent, queried where uncertain, superimposed where failure has occurred on older landslide debris
	Shallow landslide or earthflow, arrows indicate direction of failure, scarp hachured where apparent; querried where uncertain; deposit is less than 10 feet thick
	Surficial creep occurring on slopes
mudflow 1938	Mudflow, dated where documented; mudflows are generally shallow, narrow, and confined to canyons and gullies
▲ 4.5 10.27.69	Epicenter with magnitude and date(s), plotted from computer read-out for period of January 1932 to December 1972 (Hileman et al., 1973). Most epicenters are thought to be accurate within 5 to 15 kilometers



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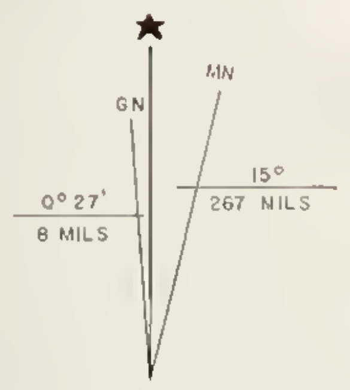
INDEX MAP



UTM GRID AND 1965 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

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GEOLOGY OF THE LAGUNA BEACH QUADRANGLE ORANGE COUNTY, CALIFORNIA

BY

WILLIAM J. EDGINGTON AND SIANG S. TAN, 1976

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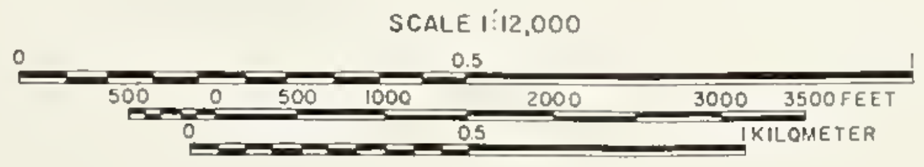

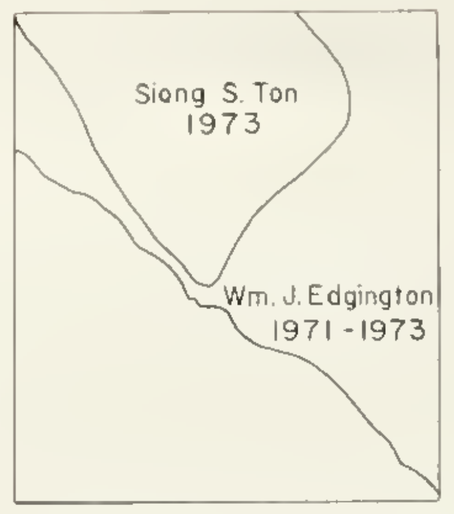

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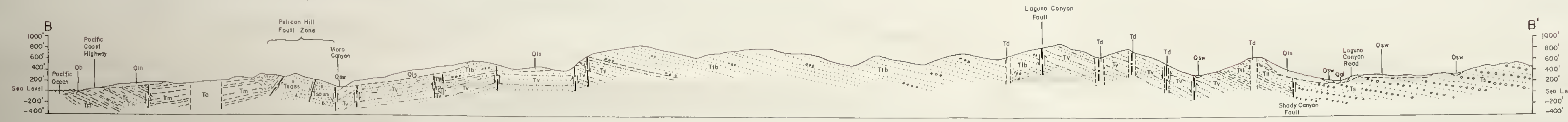

SECTION B - B'

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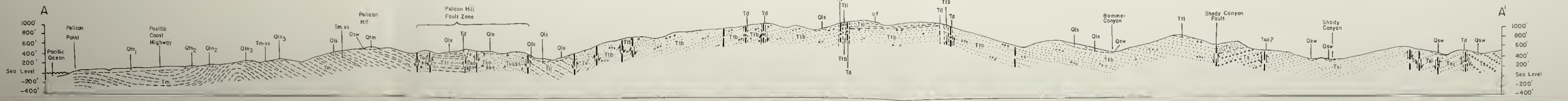

SECTION A - A'

TOPOGRAPHIC BASE MAP BY THE U.S. GEOLOGICAL SURVEY 1965

GEOLOGY MAPPED BY WILLIAM J. EDGINGTON 1971-1973
AND SIANG S TAN 1973
DRAFTED BY PETER HELANDER 1974

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